Linking Remote-Sensing Technology and Global Needs: *A Strategic Vision*

A Report to NASA by the Applications Working Group

CONTENTS

Figures

Tables

Linking Remote-Sensing Technology and Global Needs: *A Strategic Vision*

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ACKNOWLEDGMENTS

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2 INTENTIONALLY

Overview

1

In the scant 30 years since the first civil satellite was launched into space, remote sensing has profoundly affected our knowledge of the planet Earth—its continents, oceans, atmosphere, biosphere, and ice cover. We have discovered a far more dynamic and complex world than could be imagined only a few generations ago. Remote sensing is expanding mankind's vision of the Earth and of how our air, land, and oceans interact on a global scale. Such interactions affect climate and provide clues to the actions that can and must be taken if mankind is to survive and flourish—to preserve the quality of life and to extend the food supply of an expanding world population. From satellite observations of the Earth, we are now able to

- Make 3- to 5-day worldwide weather forecasts over most parts of the globe, with accuracy and coverage never before possible
- Monitor drought over large regions of the Earth, such as the African Sahel
- Measure forest fires and deforestation over millions of acres of sparsely inhabited and wilderness terrain
- Pinpoint the bioproductive ocean areas most likely to harbor feeding fish
- Use ground tracking of satellites to verify the annual shifting of the Earth's tectonic plates, potentially helpful for predicting earthquakes

The help that could be available from remote sensing is barely being tapped on a myriad of practical issues. . . .

The extraordinary progress made in space technology has outstripped our ability to use and apply this knowledge. The help that could be available from remote sensing is barely being tapped on a myriad of practical issues—land management, short-term climate forecasting, ocean resource development and management, marine operations, urban planning, crop and forest yield predictions, oil and mineral resources, and monitoring of desertification patterns.

The United States, with its huge initial investment in space technology, has led the world in pioneering the development of this field. But we are not reaping its full potential benefit. In fact, we are now in danger of losing our premier position, as other countries move aggressively to utilize the technology more effectively than we are doing. As seen in newspapers worldwide, sophisticated, highest resolution images of the nuclear disaster at Chernobyl came not from a U.S. satellite, but from the new French commercial satellite, SPOT. Japan and India now operate their own Earth satellites; both have enunciated a national goal of using these satellites to exploit the natural resources of the Earth for the benefit of their countries.

The Charge to the Applications Working Group

Aware of the importance and enormous practical value of information now being generated by remote sensing of the Earth, Congress directed NASA and NOAA in the FY 1984 Authorization Act to develop a long-term strategy and plan for their applications program "to ensure that the Nation is investing sufficiently and wisely" in this important area. This Report presents the views and strategies developed by a working group of technical advisors invited by NASA to plan such a strategy. Under sponsorship of the Remote Sensing Subcommittee of the NASA Space Applications Advisory Committee, subcommittee members and other advisors participated

The Applications Working Group set up subcommittees to plan demonstration projects in the four major applications areas: renewable resources, nonrenewable resources, ocean, and atmosphere.

during August 1986 in a week-long workshop to plan this strategic applications approach. The group members—senior-level scientific, academic, and business professionals knowledgeable about remote-sensing applications—represent the very broad applications community from government, academia, and the private sector.

NASA charged the Applications Working Group with developing a draft report that would outline a long-range, remote-sensing applications strategy for NASA's Earth Science and Applications Division (ESAD). This report, *Linking Remote-Sensing Technology and Global Needs: A Strategic Vision*, is the culmination of the Working Group's activities over a 6-month period. As requested by NASA, this strategy addresses both long-term goals for guiding NASA's applications program and measurable short-term research objectives for reaching these goals over the next decade. The Report represents a strategic approach rather than a complete plan. It is designed to provide a realistic vision for fostering remote-sensing applications, near-term milestones to help NASA focus its priorities for research, and guidelines for evaluating applications proposals.

Remote sensing has changed our perception of the Earth, helping us to understand that the Earth operates as an integrated global system. But many kinds of sensor data are not yet available to potential users. The Working Group is convinced that the key to expanding applications lies with access to information. Raw data transmitted from space must be interpreted into meaningful information. This requires the development of new and improved algorithms and models, with simulated experiments and field demonstrations to test the accuracy of the remotely sensed data as compared with ground truth data. Above all, information systems must be developed that allow users easy access to the information they need.

Focus of the Proposed Strategy

To meet this paramount need for information, the Working Group focused the proposed applications strategy on providing information to users, rather than on technology or hardware development. The goal of the Applications Strategy is to develop through demonstration projects, by the end of the next decade, integrated information systems that will allow private industry (including value-added industries), operational agencies, and scientific research communities to exploit effectively the data taken by Earth-observing satellites.

The proposed system builds on existing or planned information systems, networks, and computer facilities within both NASA and other government agencies. It is a strategy designed to serve users at multiple levels, meeting the widely varying needs of the applications community. These needs can be as simple as help with catalogs and information extraction formulas for a company using its own models and computer system. For others, the need can be for highly complicated scientific assistance from NASA researchers with multidisciplinary, multitemporal data and four-dimensional global climate models.

The Working Group selected five high-priority application topics for NASA demonstration projects; the data, algorithms, models, and results in each area will become the first modules of the proposed information system. Potential applications are many and varied: Which particular questions deserve the earliest, most concentrated attention? The Applications Working Group set up subcommittees to plan demonstration projects in the four major applications areas: renewable resources, nonrenewable resources, ocean, and atmosphere. The objectives chosen involve the development of new information techniques and systems to provide:

- Global mapping of arable land degradation showing losses from erosion, salinization, and desertification
- Global mapping of forested versus nonforested areas, providing a basis for local forest production and yield estimates
- Evaluation of the potential regional occurrence of strategic nonrenewable raw materials on a global basis
- An operational hindcast, nowcast, and short-term (up to 1 week) forecast system, with mesoscale resolution, for such important physical variables in the oceanic and atmospheric planetary boundary layers as wave height, surface winds, sea surface temperature, and mixed layer depth
- A global research atmospheric system for weekly, monthly, and seasonal values of such climate parameters as temperature and humidity, thereby improving the capability for global climate monitoring and prediction

To implement this Report, NASA will need to set up new institutional agreements and relationships with other agencies and seek advice from the user community. The Report, then, is intended to be used by NASA as a basis for developing the complete NASA plan, including implementation strategies, working agreements, schedules, and budget requirements. As an outcome of the plan, NASA is expected to solicit applications research proposals from universities, industry, operational agencies, and the scientific research community. This Report is intended as a strategy to guide NASA's priorities, not as a national plan.

Proposed Applications Information System

- Will serve multiple users in Federal agencies, academic institutions, and private industry
- Will permit access to disparate data sets at many geographic locations within the research and applications community
- Will provide the capability for performing a complete spectrum of studies, from specific individual projects to broad interdisciplinary problems
- Will provide catalogs and data from U.S. and foreign instruments, academic and research archives, and other information sources

Current Applications Environment

2

The present time is ideal for developing an Applications Information System. Space technology has reached an appropriate level of maturity to warrant such a step. During the 1960s and 1970s, the United States made extraordinary progress in developing both spacecraft and sensors that permitted global observations of the Earth's surface, ocean, and atmosphere from space. NASA's research satellites Landsat and Seasat showed the enormous potential of this technology. Polar-orbiting weather satellites became operational in 1966, and geostationary environmental satellites were launched in 1974.

In the coming decade, the usefulness of remotely sensed data will be limited not by technology, but by user access to the data collected in space.

The science of remote sensing has emerged and grown during the 1980s, with emphasis focusing on the development of improved statistics and more sophisticated models, particularly two- and three-dimensional numerical models. New four-dimensional models reflecting time can now be constructed, which will help us to understand the interactions at such boundaries as those between atmosphere and ocean. Advancement in computer technology, combined with satellite and in situ observations, is making possible the development of these ever more sophisticated global models. Data management systems can now be created that are capable of handling large quantities of interdisciplinary and multidisciplinary data.

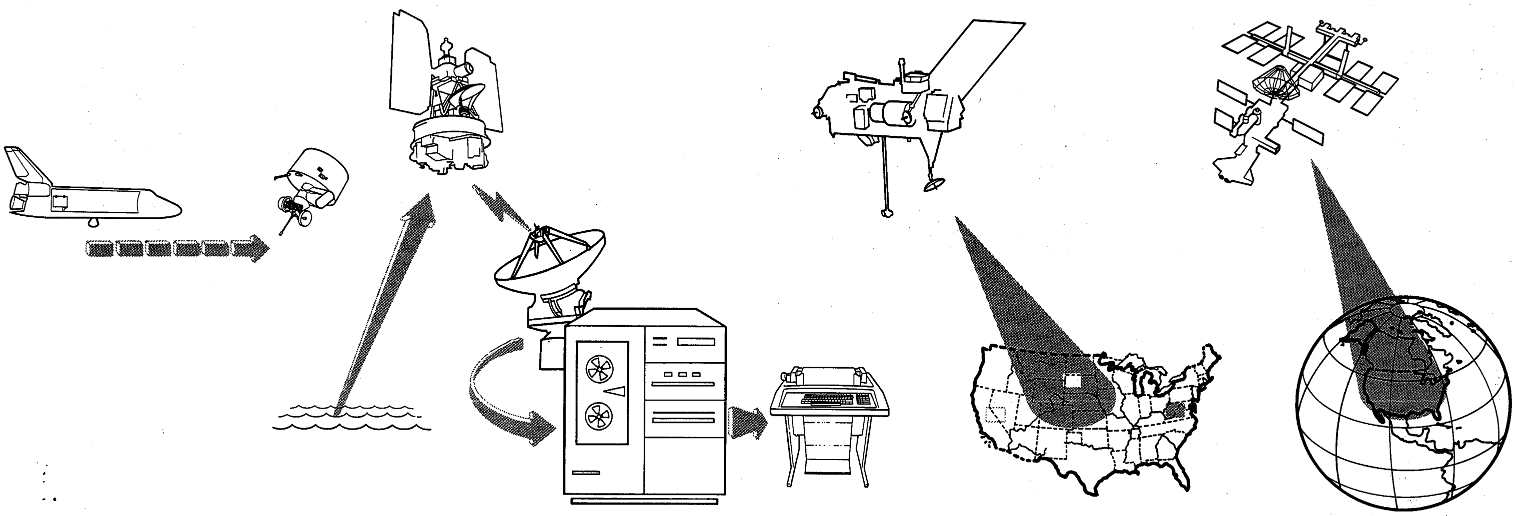
By the 1990s, with launch of the Polar Platforms providing continuous data streams of more than 10 trillion bits per day, it will be possible to understand and transfer a wide range of Earth science findings into the practical domain. In the coming decade, the usefulness of remotely sensed data will be limited not by technology, but by user access to the data collected in space.

The decade from 1987 to 1996 will thus be a time of exciting expansion in global data. By planning now, we can capitalize on these coming opportunities, identifying the types of data that, if extracted and archived, would offer the greatest economic and other benefits for potential users. Perhaps even more crucial, linkages can be built now to ensure that needed connections between the multiple relevant data sources are in place, ready to be tapped in the 1990s. These steps will build and enhance the information infrastructure of remote sensing, so a range of applications can be done.

This Applications Strategy sets up an overall framework—an information system—for making the entire spectrum of remotely sensed and other pertinent data more available to the applications community. Each near-term objective defines one important, useful area of applications information. Meeting each objective will answer the need for research to make space-based data more meaningful in that given applications area. The information, algorithms, and models generated by the demonstrations will form subsystems or modules in the evolving Applications Information System. Structure of the overall information system will be driven by the specific applications selected by NASA now and in the future. Demonstration results will be available to all users.

Any strategies designed to maximize the data available to potential future users will be valuable in the coming decade. But the strategy developed by the Applications Working Group addresses—and potentially resolves—a whole series of issues that currently limit access to data. For example, in addressing the five specific, high-priority objectives, the Applications Strategy provides the following types of assistance to users:

Remote-Sensing Technology Development



	1960s	1970s	1980s	1990s
PROGRAM FOCUS	**TECHNOLOGY DEVELOPMENT**	**INITIAL MEASUREMENTS AND TECHNOLOGY DEMONSTRATIONS**	**SCIENCE/ APPLICATIONS DEVELOPMENT**	**EARTH AS A SYSTEM**
	Launch of first spacecraft Development of first sensors	Institution of data processing Development of algorithms	Use of limited models Understanding the science	Archiving of/access to global data Acquisition of super computers (Class VII) at major centers Access to multi-disciplinary data sources
MILESTONES	Transfer of technology begins Introduction of technologists into program	Validation of remotely sensed measurements Introduction of scientists into program	Increasing modeling sophistication from simple to 4-dimensional global models Expansion of applications researchers in program Beginning of U.S. commercialization policies for land satellites	Technology of Space Station in place (combined science/ operational sensors) Period of data synthesis and global modeling Use of remotely sensed data for resource decision models
ISSUES OF CONCERN	Nature of Earth applications Scope of applications	Assessment of benefits/costs Development of constituencies for remotely sensed data	Need for broader data access/acceptibility Need for studying Earth sciences as a global system Need for integrated information system as next scientific step Need for multisystem multisensors as next advance in remote sensing	Need for increased institutional arrangements Allocating the cost of science

- Identifies specific Earth science data collected by NASA research satellites—both current and planned—that need to be accessible for the outside community as well as for NASA mission researchers
- Makes NASA research data available to the weather/climate forecast systems by means of new high-rate data links, which will be valuable initially for the meteorological and oceanic operational communities and ultimately for a range of end users
- Identifies specific data from NOAA operational satellites that need to be retained and archived for both applications and research purposes
- Provides access, through catalogs or direct means, to space-based research information from the National Science Foundation and university sources
- Identifies and catalogs a range of relevant data sources important for specific applications users, such as ground-based measurements, demographic data, and maps showing geopolitical boundaries
- Provides opportunities for private firms, through shared NASA demonstration projects, to receive needed research help from academic sources in developing algorithms and models
- Provides an ongoing mechanism by which government operational agencies, particularly NOAA, can benefit from NASA's research and technological expertise in such areas as development of geophysical algorithms and modeling of global atmospheric circulation

Information, algorithms, and models generated by the demonstrations will form subsystems or modules in the evolving Applications Information System.

Contributions of Remote-Sensing Technology

Unique—Providing new perspectives on the Earth on a scale never before possible

Powerful—Providing a global view of the planet, while simultaneously measuring interactions between components of the climate system

- ★ Transport of heat by ocean currents
- ★ Absorption/release of moisture by vegetation cover
- ★ Distribution of atmospheric trace gases and pollutants
- ★ Improved understanding of the hydrological and biochemical cycles

Land

Achieved or potential improvements in

- Global crop prediction, yield estimates, and crop stress assessments
- Global monitoring of forest distribution, forest health and disease, and fire hazards
- Quantifying effects of natural and man-made disasters
- Managing of water resources, water pollution, and flooding
- Mapping for cartography and land-use planning
- Identifying global occurrences of geological, mineral, soil, and geothermal resources

Solid Earth (Satellite Tracking)

Achieved advances in

- Measuring motions of Earth's tectonic plates
- Knowledge of the Earth's rotation, including polar motion
- Knowledge of the shape of the Earth and its gravity field
- Measuring the global magnetic field with uniform precision and accuracy

Oceans

Achieved advances in

- Monitoring variations in global ocean circulation and the annual cycle of polar sea-ice
- Measuring sea-surface temperature distributions, fronts, and ocean currents
- Determining global surface wind speed and directions over oceans
- Knowledge of phytoplankton distributions and ocean pollution
- Knowledge of the ocean geoid and currents, tides, eddies, and surface wave height
- Discovering unexpected insights, such as organized internal wave motions persisting over great distances and rapidly developing open-water areas within Arctic sea-ice

Atmosphere

Achieved advances in

- Ability to predict weather and monitor major weather systems on a global scale
- Ability to understand the interactions among components of the Earth system (atmosphere, oceans, ice regions, and land surfaces)
- Measuring and understanding of large-scale anomalies in atmospheric circulation (e.g., effects on global weather of El Niño, the anomalous sea-surface temperatures in the tropical Pacific)
- Demonstrating the value of climate and environmental interaction studies
- Measuring, understanding, and predicting the effects of trace gases in the atmosphere on the ozone layer and long-term climate
- Discovering unexpected insights, such as the annual hole in the ozone layer over the Antarctic and the effect of aerosols on Earth's radiation balance

Recommended Program Strategy

3

The information system concept is . . . not new. It simply introduces the applications agenda into the planning for NASA's new information system. . . .

By the mid-1990s, with the advent of the Space Station Polar Platforms carrying a combined load of research and operational sensors, an avalanche of raw data will pour down to Earth. Scientists will use this flood of information to look at such basic questions as how Earth systems operate, how man-made pollutants affect Earth's protective ozone layer, and how rainfall in the tropics affects global climate. Such knowledge has enormous long-term benefits for life on Earth.

These data can be made available not only to scientists but to the thousands of individuals, companies, and government groups who can use them. The uses are legion: for the local irrigation district managing watershed problems, for the forest firm using a microcomputer to predict forest yields, for the shipping company concerned with both safety and fuel savings, for the fisherman hoping to increase his daily catch. The payoff from the investment being made in space technology will come from our ability to provide information that meets such practical needs as these.

The Goal: A Strategic Vision

The vision for the future is an Applications Information System available to all users—whether a large government agency or a small local firm—that will afford overall benefits for the public good and further the economic interests of the United States. This system will provide broad and meaningful access to all types of remotely sensed data and will involve the development of new networks, working arrangements, and interagency, possibly also international, agreements.

As a first step, the Working Group proposes as its overall goal

to develop and demonstrate, by the end of the next decade, integrated information systems that will allow private industry, operational agencies, and scientific research communities to exploit effectively the data taken by Earth-observing satellites.

This proposed integrated system would provide not just general access to research and operational data but would ensure that appropriate, helpful calibrations, algorithms, and models are available to users. The system would also foster development of remote-sensing products.

The projected Applications Information System would be designed to fit as one part of the integrated Earth sciences information system now being planned by NASA for Eos, the Earth Observing System of the 1990s. The information system concept is therefore not new. It simply introduces the applications agenda into the planning for NASA's new information system, which is expected to integrate both scientific and operational data as well as pertinent data from other sources.

Plans were predicated on the following crucial operating assumptions:

- There will be an operating Space Station beginning in the mid-1990s.
- Roles and missions of government science agencies will remain as legislated and as currently performed.
- Operational remotely sensed data will continue to be available.
- NASA's Earth Science and Applications Division programs will continue to be science-driven.

In the renewable and nonrenewable resources areas . . . users are expected to include many individuals, small companies, and university researchers using microcomputers.

- The budget of NASA's Office of Space Science and Applications will remain relatively constant.

The Objectives: Steps Toward the Goal

Building an Applications Information System accessible to a wide range of users needs to be done incrementally, not only to stretch out costs in the current budget climate but, more important, to provide a chance to test and fine-tune the system as users access information. To demonstrate the feasibility and usefulness of the projected information system, only a limited number of high-priority applications objectives could be selected. These objectives were chosen so that, in toto, they would demonstrate the following important characteristics:

- Capacity to meet needs of all types of applications users, including the research community, operational agencies, and end users (individuals, companies, the value-added industry, government entities)
- Capacity to provide near real-time data for the operations community, slightly delayed and historical data for researchers and end users, and related types of data for all users
- Capacity to provide useful applications pertaining to all Earth science disciplines, particularly from land, ocean, and atmospheric sensors
- Potential for gaining useful scientific knowledge from the applications demonstrations, deriving synergistic benefits for both science and applications

Although five applications objectives were chosen to demonstrate separate modules and capabilities of the proposed information system, each also stands as an important demonstration in its own right, representing critical issues of strategic and human importance. Each applications objective is a topic of high national or international priority, worthy of immediate and concentrated attention and capable of showing significant potential gain from remote-sensing techniques.

For each objective, a strategy has been developed to guide NASA over the near term. These strategies specify measurement and model requirements, information systems requirements, demonstration projects and schedules, and technology transfer objectives and recommendations. The outcomes of each demonstration—the data, algorithms, and models—will become modules in the planned, evolving information system. More detailed information about these strategies appears in Section 5.

Renewable/Nonrenewable Resources Objectives

In the renewable and nonrenewable resources areas where there are no large operational satellite systems, users are expected to include many individuals, small companies, and university researchers using microcomputers. The resources areas depend heavily on imagery and require demonstration projects before the techniques for extracting information can become operational. The chosen objectives focus on the following:

- *Renewable Land Resources*
  Define and validate by 1995 new information systems that support global mapping of arable land degradation every 5 years, showing losses due to erosion, salinization, and desertification
- *Renewable Forest Resources*
  Define and validate by 1995 new information techniques that support global mapping of forested versus nonforested areas every 5 years, with local sample mapping of forest production and yield estimates for the four major types of forest ecosystems
- *Nonrenewable Strategic Resources*
  Develop and validate by 1993 new data management systems and information extraction techniques for evaluating the potential occurrence of strategic, nonrenewable raw materials on a global basis, specifically the chromium, cobalt, manganese, and platinum-group metals needed to manufacture high-technology products

These particular objectives are serving as test cases. The remote-sensing techniques being demonstrated, if they prove successful, will be broadly applicable to other applications. For example, four strategic raw material groups have been chosen to test whether their potential occurrence can be shown by use of remote sensors combined with conventional data. If the technique is successful, it can be applied to other minerals and would presumably be used on a routine basis in the latter 1990s after launch of the NASA/NOAA Polar Platform.

Ocean/Atmosphere Objectives

Regarding the ocean/atmosphere, the objectives are similar; these areas have a longer remote-sensing history with several operational agencies already in place, such as the National Oceanic and Atmospheric Administration (NOAA), the Navy's Fleet Numerical Oceanography Center (FNOC), and the Air Force Global Weather Central (AFGWC). For these objectives, NASA will play an intermediate role by providing gridded, digitized data and high-rate data links for sharing computational facilities among various centers.

During the initial and demonstration phases, users will be operational agencies, major government and university research programs, and the international community. End users will include the commercial market for weather services, the fishing and shipping industries, search and rescue missions, pollution management, and the value-added and offshore industries. The following objectives were chosen for the ocean/atmosphere areas:

End users [ocean and atmosphere] will include the commercial market for weather services, the fishing and shipping industries, search and rescue missions, pollution management, and the value-added and offshore industries.

- *Ocean—Hindcast, Nowcast, and Forecast*
  Define and validate by 1995 an operational hindcast, nowcast, and short-term (up to 1 week) forecast system, with mesoscale resolution, for such important physical variables in the oceanic and atmospheric planetary boundary layers as wave height, ocean surface and atmospheric temperatures, currents, and surface winds
- *Atmosphere—Four-Dimensional Data Assimilation*
  Develop and validate by 1993 a global research atmospheric system for weekly, monthly, and seasonal values of such climate parameters as temperature, humidity, wind components, soil moisture, ice and snow cover, precipitation, and surface and atmospheric albedo

The ocean/atmosphere objectives are designed to provide technical advances in long-range weather and short-range climate forecasting capability. The strategy incorporates a number of new parameters, particularly wind and wave height data, that will soon become available with the launch of the Ocean Topography Experiment (TOPEX) and NASA's scatterometer (NSCAT).[1] The strategy uses in situ data that will be collected by international research programs, such as the Tropical Ocean Global Atmosphere (TOGA) program.

This objective also helps to define NASA's ongoing technical role within the operational system, specifically in interfacing research data and in putting the data into an assimilated data system. The interface, which occurs primarily with NOAA, is dealt with in this report as a technical rather than a political interface.

Recommendations for Implementation

This strategic approach reflects many urgent needs expressed by potential users of remotely sensed data. Because these users represent such a diverse, dispersed group, they frequently remain unaware of how they could profitably use or access such data. For this reason, the Applications Strategy needs care not only with its content but with how it is implemented. The Working Group makes the following suggestions to NASA for implementing the long-range Applications Strategy.

1. NASA should immediately state its intention to support remote-sensing applications research activity and to demonstrate its commitment by issuing a call for proposals.
2. NASA should develop mechanisms to involve users heavily in its R&D program and to state this intention publicly; users should be involved at all stages from inception through implementation.
3. NASA should encourage the use of interdisciplinary data in its applications R&D program, including support to help users and the research community as they develop both an awareness of such data and expertise in its accession and use.
4. NASA should plan early for the overall engineering concept of the Applications Information System, so that both the system's initial development and its evolution will be aligned with the needs of the individual disciplines.
5. NASA should establish an Information System Oversight Group representing the disparate user community to ensure coordination, maximum usefulness, and standardization of the system design.

[1] NSCAT was originally scheduled to fly on the Navy Remote Ocean Sensing System (N-ROSS) which was cancelled in late 1986; this decision is being reconsidered as of April 1987. NASA still plans to fly NSCAT in the early 1990s on N-ROSS or an alternative vehicle.

NASA needs to be assured that the services they develop are meeting a real need for users . . . .

6. NASA should promptly address the major management issues that must be resolved in order to establish an Applications Information System.
7. NASA should promptly adopt and implement the evaluation criteria contained herein and use it in the evaluation of the applications proposals.

Additional Implementation Issues

To implement the applications plan, NASA will need to deal with a range of institutional, managerial, and proprietary issues; with user attitudes; and with the selection of applications research proposals.

Management and Institutional Issues

The remote-sensing field is complex, involving many organizations—government operational agencies such as NOAA and Navy; the National Science Foundation; international scientific bodies; university researchers; end users; and the commercial sector represented by the EOSAT Company and the value-added industry. The Applications Strategy both includes and serves all these groups, which will require gaining their cooperation and, in many cases, setting up new working agreements.

In addition to linking the involved agencies, restrictions will exist concerning what kinds of data can ultimately be included in the information system. The rights of the commercial sector to sell certain types of data without unfair government competition will need to be respected. The proprietary rights of individual companies to retain some types of information will also need to be defined and protected, often on a case-by-case basis within the demonstration mode. Sample issues needing NASA's attention include:

- Institutional agreements with EOSAT regarding access to Landsat data and other commercial issues
- Institutional agreements with operational agencies, particularly NOAA, which would include shared personnel and facilities during the development and technology transfer phases
- Agreements with NOAA on retention of data from their observational systems
- Analysis to ensure compatibility of the Applications Information System with the proposed Eos system
- Agreements to conduct ground tests pertaining to minerals on sites in foreign countries
- Agreements for acquiring data from foreign satellites and international projects

User Attitudes

In the present constrained Federal budget climate, users—whether Federal agencies in need of NASA research expertise or individual private companies—will be expected to share costs or to pay for information products and services. The current environment therefore exacts close communications between NASA and the user community. Remote-sensing services cannot be provided in a vacuum; NASA needs to be assured that the services they develop are meeting a real need for users, that there is a viable market, and that this service will not compete with products available from the private sector.

The Working Group feels great concern about how important it is for NASA to involve users at all stages in the development of the Applications Strategy. To provide this interface, the Working Group recommends appointment of an oversight committee to help plan the Applications Information System initially and as the system evolves. In addition, a separate working group should advise NASA as each demonstration project is set up and implemented.

Selection of Applications Research Proposals

A framework for helping NASA select participants in the demonstration phases of the Applications Strategy has been defined with some care by the Working Group. Participants will be selected through NASA's research proposal program. In a broad sense, all applications proposals will be expected to forward NASA's goals and objectives as well as to meet national needs. Other questions to be addressed include:

- Does the research represent a step forward, needed now and over the long term?
- Will the new techniques or models be flexible and adaptive for diverse applications?
- Is the needed data identified and available?

- Can the proposed technology be used economically?
- Is the state of science in related fields sufficiently advanced to support it?
- Is the research carefully planned on a phased-in basis, with clear-cut intermediate points for review and decisions?

Applications proposals will be divided into two categories: (1) public domain proposals submitted by Federal agencies, universities, or the private sector, and (2) commercial joint venture proposals usually submitted by private sector and university researchers. For commercial joint venture proposals, applicants will be expected to share costs with NASA. Criteria recommended by the Working Group for evaluating NASA applications proposals are further discussed in Section 7.

Benefits of the Applications Strategy

4

An inherent challenge of the U.S. space program is its dispersion. Remote-sensing operations are scattered among many Federal agencies, including not only NASA but the Departments of Commerce (NOAA), Defense, Energy, Interior, Agriculture, and others. NASA contains not only the most advanced technological and engineering expertise available in the world, but equally strong research capabilities in the Earth sciences. What is missing are the institutional and procedural links between NASA's research capabilities and other Federal agencies, as well as access to this repository of information by outside users.

The proposed information system provides a viable structure for linking NASA's research strengths to Federal operational systems and to outside users. The networking of the information system provides such linkage by both its nature and design. In addition, in the planning and operating of an Applications Information System, NASA would have a vehicle for regularly receiving the current perspectives of applications users.

Virtually all national and international bodies in the Earth sciences are now calling for a new, integrated approach to studying the Earth.

Attributes of the Strategy

Virtually all national and international bodies in the Earth sciences are now calling for a new, integrated approach to studying the Earth. Within this context, a highly significant activity is the initial report of the Earth System Sciences Committee (ESSC), which was established in 1983 by the NASA Advisory Council. The ESSC mission, now nearly complete, is to review the science of the Earth, to recommend an implementation strategy for global Earth studies, and to define NASA's role within such a program.

The proposed Applications Information System is not only consistent with ESSC recommendations, but complements the ESSC report by focusing on specific applications issues addressed only in broad scientific terms within that document. The global systems approach proposed by the ESSC includes the following recommendations to NASA, all of which form a valuable and essential framework for the proposed Applications Strategy:

- The Earth needs to be understood as a single, interrelated system, with research attention given to both the separate research disciplines and to how the major geophysical domains (biota, atmosphere, and oceans) interact.
- The study of global change requires an integrated research program based on long-term, continuous global observations of the Earth.
- An advanced information system will be needed to enable the international scientific community to process global data and to permit efficient data analysis, interpretation, and quantitative modeling of Earth systems processes.
- Worldwide study of the Earth will necessitate strengthened coordination among researchers of many countries, as well as collaborative international agreements.

NASA's Earth system science plan and the proposed Applications Strategy have in common a similar program philosophy, shared observing system requirements, a need for historical archives, and a need for access to an information system at

The applications objectives represent shorter term, urgent problems with substantive scientific content.

multiple levels that contains algorithms and models. In applications, there can be a requirement for either real-time data or for the longer term, delayed-time data usually used in scientific study. However, scientists may also benefit from access to real-time data that are not currently archived by the operational systems. The proposed Applications Strategy establishes particular sets of near-real-time and real-time data to be targeted for archiving and retrieval—information of value to scientists as well as applications users.

Overlap also exists between the proposed applications objectives and areas of current concern to science. Knowledge gained from the proposed applications demonstrations can benefit scientists in all areas proposed for study, including the following:

- Land degradation—impact of varying vegetation on surface energy and the interactions of man-land-surface processes with climate in specific biomes
- Forests—land use and biome productivity, effects of deforestation on long-term climate
- Strategic minerals—use of remote sensing for identification of surface materials and to provide insight into the tectonic and geochemical processes that shape the Earth's crust
- Ocean—issues of large-scale ocean circulation on and below the surface, including how the atmosphere takes up heat and surface moisture from ocean surfaces and how this affects climate
- Atmosphere (climate)—the defining of climate state and its anomalies, using retrospective data and data delivered too late for daily forecasts

Appropriateness of the Strategy in Long-Term NASA Plans

The proposed applications strategy complements the ESSC report, which will be used to guide NASA's long-term scientific directions. The applications objectives represent shorter term, urgent problems with substantive scientific content. The strategy serves to focus short-term NASA priorities and to provide a structure for ongoing applications projects within research planning of the Office of Space Science and Applications (OSSA).

The proposed Applications Information System offers significant advantages for the broader OSSA program. These include the following:

- Practical assistance in guiding the evolution of the Eos information system now being planned. The Applications Information System is a precursor to and compatible with the planned Eos system.
- Responsiveness to the recommendation of all NASA's advisory committees for an integrated data base system that can provide widely dispersed access to multidisciplinary information for both research and applications purposes.
- Experience useful in preparing instruments for the Space Station Polar Platform, the chief vehicle for research and operational programs in the mid-1990s. Although the applications objectives were not designed to justify any particular measurement programs, the planned demonstrations do in fact require the type of sensor measurements planned for deployment on the Polar Platform.
- Identification by application users of areas where new technology or techniques are required, which will help NASA in their advanced planning of new and improved instruments.
- Flexibility of the proposed system, as a result of its modular structure, for allowing NASA to achieve particular goals or milestones. Timing is less important than the overall concept of the approach, so that the number and schedule of applications modules can be varied.
- Adaptability of the approach to fit NASA's budget constraints, also permitting the shifting of priorities to take advantage of potential new applications opportunities and needs as they arise. The system can be started on a modest scale and evolve gradually, incorporating new technologies as they become available.
- Definition of an ongoing research role for NASA within the large NOAA/Navy/Air Force operational systems; this role is consistent with NASA's legislative mandate.

NASA's applications approach will also encourage and support use of remotely sensed data by the private sector—one of NASA's long-range goals. Individual firms need research help to interpret data from space and to develop meaningful algorithms and models. Such help will be engendered by cooperative proposal efforts combining university with private ventures. Users who participate in the program will become familiar with and attuned to using and merging geocoded, digitized data. This training and experience will demonstrate the value of remotely sensed data to both individuals, such as geologists, and to industrial managers.

As a much broader community is introduced to the information obtainable from space, demand for such services will increase. The demonstrations themselves, along with later access to the information system, will enhance the commercial viability of all remote-sensing enterprises. This expanded user base could certainly benefit the EOSAT Company, set up to commercialize the U.S. land remote-sensing system, and will also assist the value-added industry (private companies that market their expertise in interpreting satellite data for specific business purposes).

The demonstrations themselves, along with later access to the information system, will enhance the commercial viability of all remote-sensing enterprises.

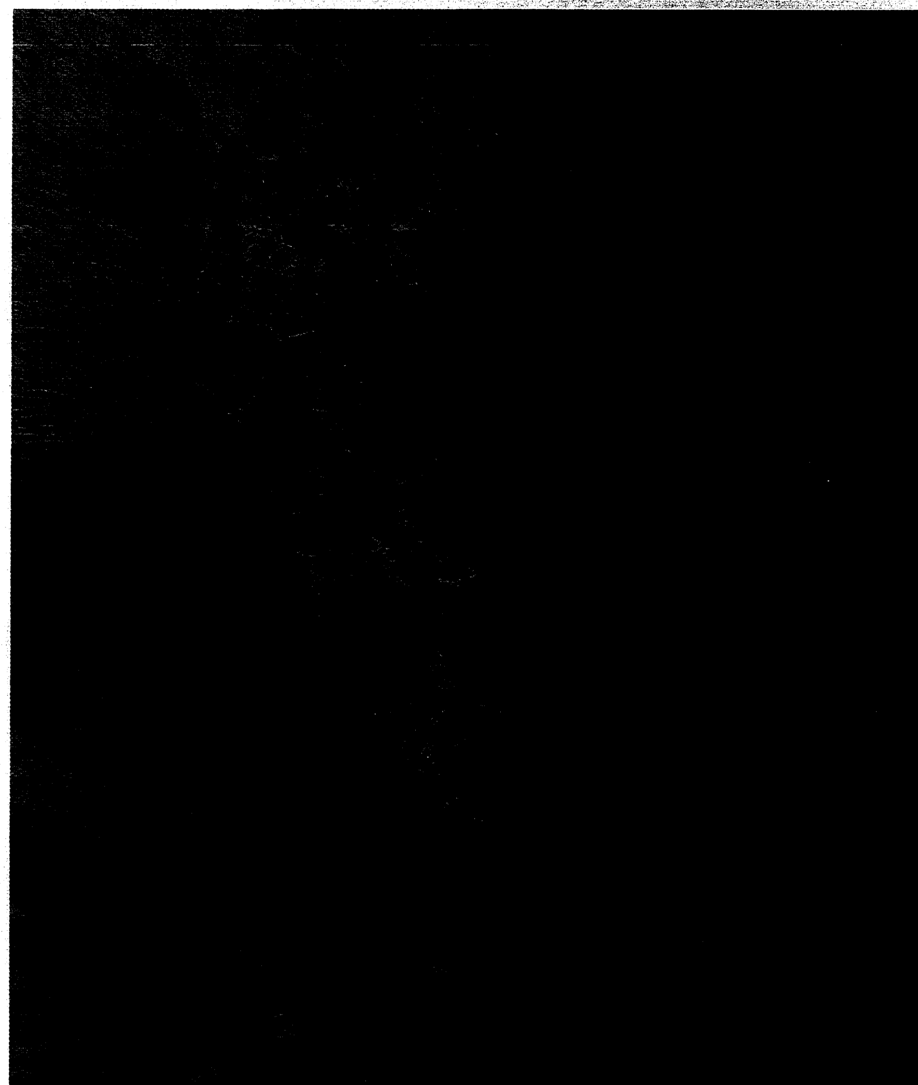
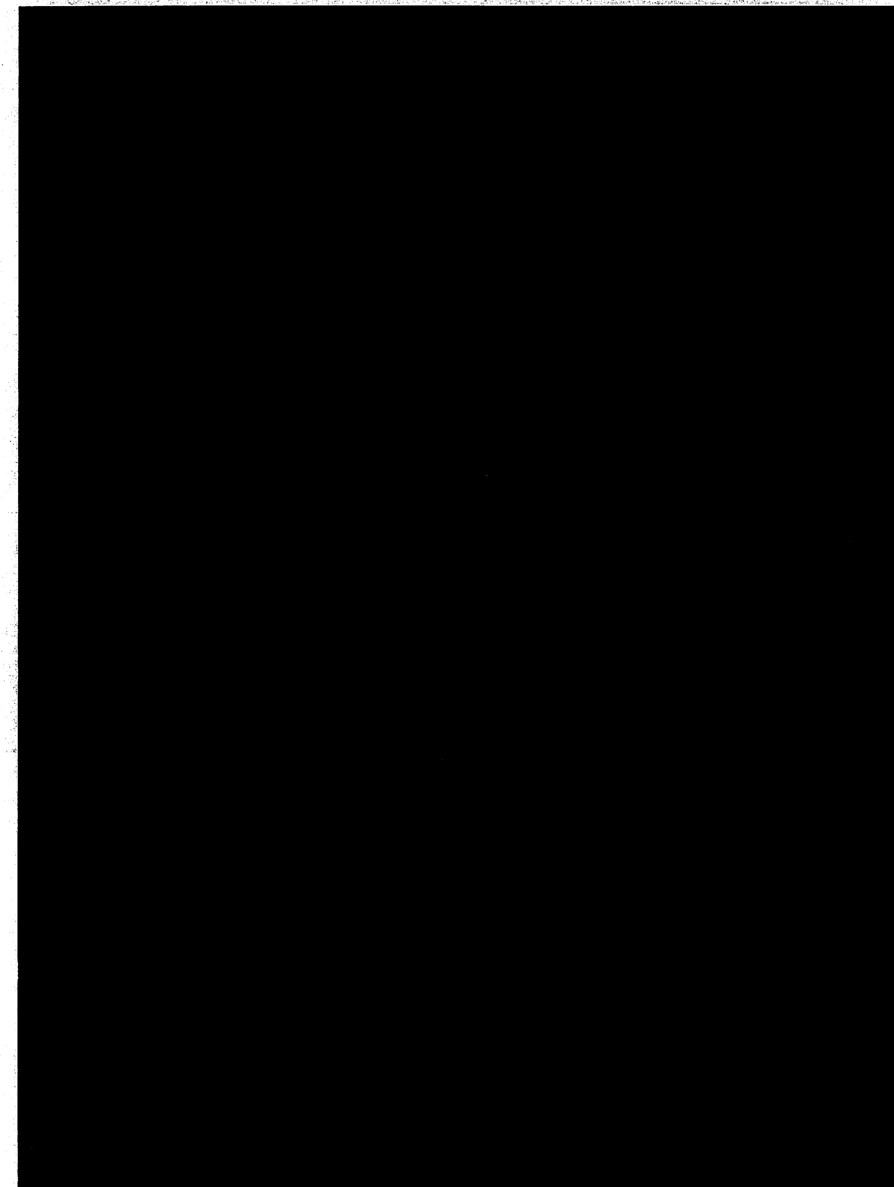


Plate No. 1 This Thematic Mapper false-color image of the Silver Bell Copper Mine illustrates how multispectral data can be used to locate mineral deposits. The yellow-orange band running from top to bottom at the center encompasses an area believed to contain large surface concentrations of iron oxide and clay.
CREDIT: JET PROPULSION LABORATORY



1979

1980

1981

1982

1983

Plate No. 3 Movement of heat by winds and ocean currents over the globe plays an important role in changing weather and climate patterns. Tropical Pacific sea-surface temperature patterns, averaged over each January for 5 consecutive years, are shown in these Scanning Multifrequency Microwave Radiometer images. Note the striking absence in 1983 of the cool tongue of water (in blue) normally found along the equator. The 1982-83 images reflect the strongest El Niño of this century. CREDIT: SEA SPACE

Plate No. 4 A perspective view generated from SIR-B data of Mt. Shasta, one of the Cascade volcanoes located in northern California, is shown here. Two stereo SIR-B images of the 14,000-foot mountain were combined to create a digital topographic map, which was then used to reproject one of the images into the scene that would have been seen by a camera located in an aircraft at 20,000 feet. The colors are proportional to radar brightness, from dark green (radar dark), through pink, to white (radar bright). The relief has been exaggerated by 50% in this view.
CREDIT: NASA

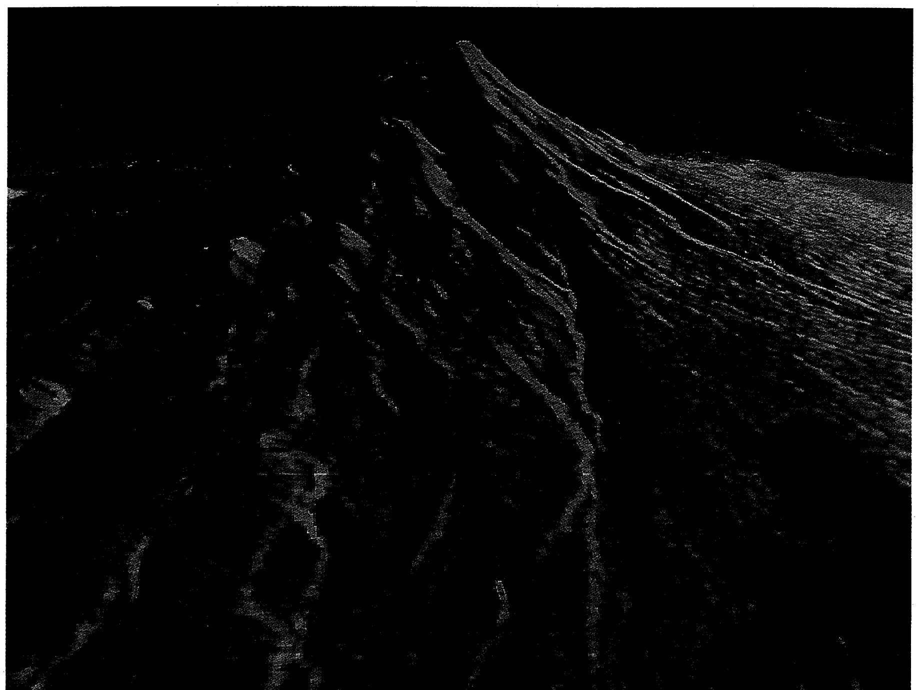


Plate No. 5 This image of Nairobi, Kenya, and the surrounding countryside was taken by Landsat TM (bands 7, 4, 3) on August 27, 1984. The green areas are vegetation.
CREDIT: ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN

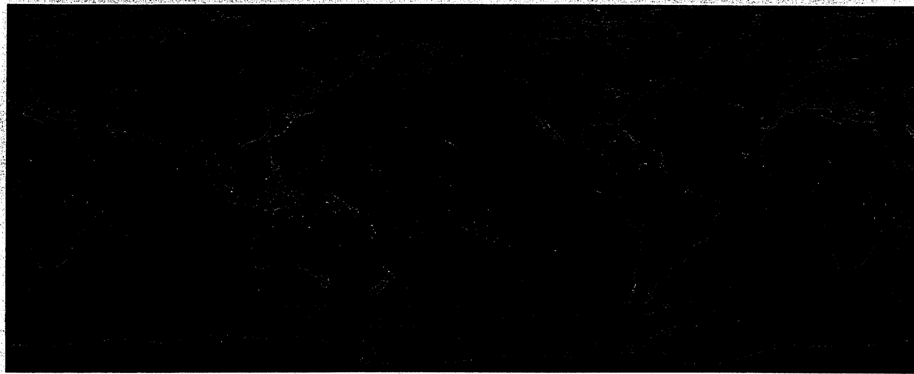


Plate No. 6 The images shown here were derived from the High Resolution Infrared Sounder (HIRIS) and the Microwave Sounding Unit (MSU) on board a NOAA polar-orbiting weather satellite. By measuring the radiation from the atmosphere and the Earth's surface, these sensors can monitor month-to-month and year-to-year changes in global surface temperature.

(Top) This photo, taken in January 1979, shows the extreme cold (blues and greens) being experienced in the Northern Hemisphere (−30°C [−22°F] in Siberia and Canada; less than 0°C in the northern United States) and the summer temperatures in the Southern Hemisphere 20° to 30°C [68° to 86°F]. Generally in the subtropics of both hemispheres, ocean currents cause the western sides of the oceans to be warmer than the eastern sides.

(Middle) Taken in July 1979, this photo shows the warming of the Northern Hemisphere (10° to 20°C [50° to 68°F]). Note the hottest areas, equatorial Africa and India, contrasted to the colder Himalayan Mountains. At this time of year in the Southern Hemisphere, Antarctica is much cooler than the Arctic Circle.

(Bottom) This photo depicts temperature differences between January and July. As can be seen from the dark blue and brown, the greatest warming and cooling occurred over land: up to 30°C changes in both hemispheres. Ocean temperatures, by contrast, rarely increase more than 8° to 10°C (14° to 18°F).
CREDIT: JET PROPULSION LABORATORY

Plate No. 7 This image made by the Space Shuttle Discovery captures the first paired typhoons photographed from space, Odessa (left) and Pat (right).
CREDIT: NASA

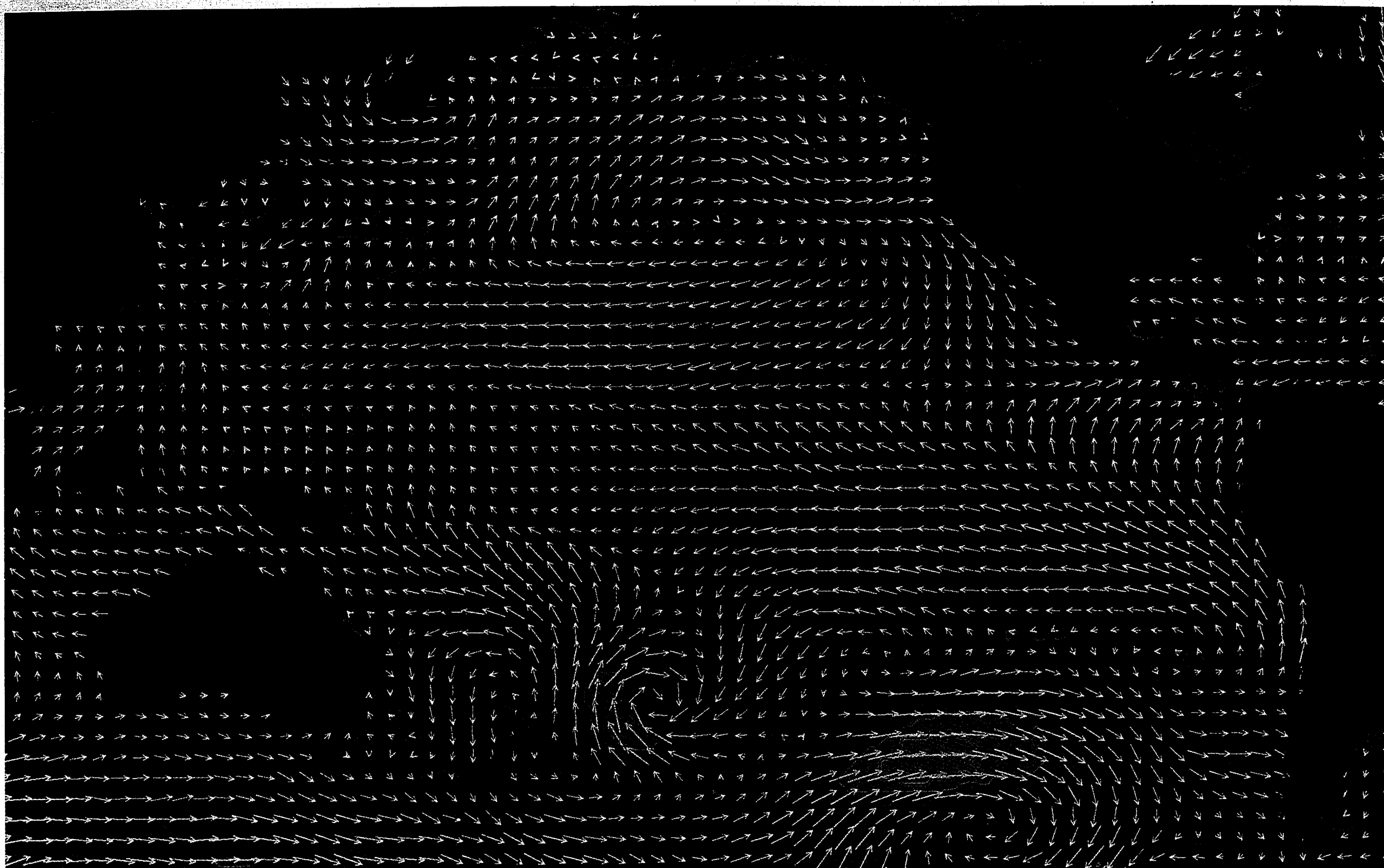


Plate No. 8 Sea-surface winds affect the exchange of heat between the atmosphere and the ocean. Past observations of marine winds have been collected by ships and have therefore been limited in both area and number. This Pacific Ocean segment of a global windfield map for September 6-8, 1978 was produced from measurements derived from the radar scatterometer (arrows shows wind directions; large arrows indicate greater wind speed).
CREDIT: JET PROPULSION LABORATORY

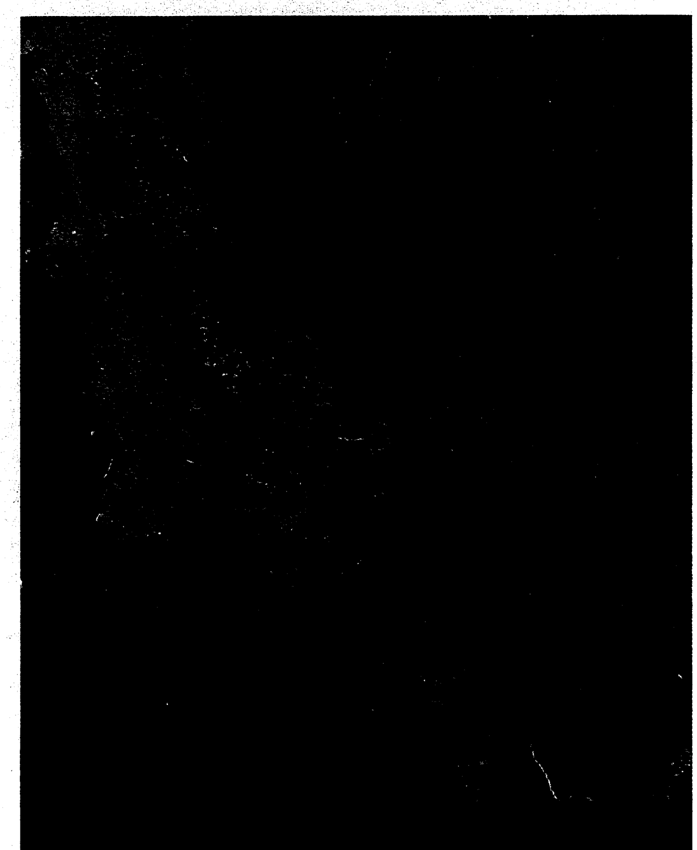


Plate No. 9 Major changes in land conditions over May 10 to June 13, 1979, are shown in this geometrically corrected image of California, derived from the Coastal Zone Color Scanner. Land condition changes include reduction in snow pack (dark blue), senescence of green grassland vegetation (orange-yellow), and wildfires (black within the colored part of the illustration).
CREDIT: ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN

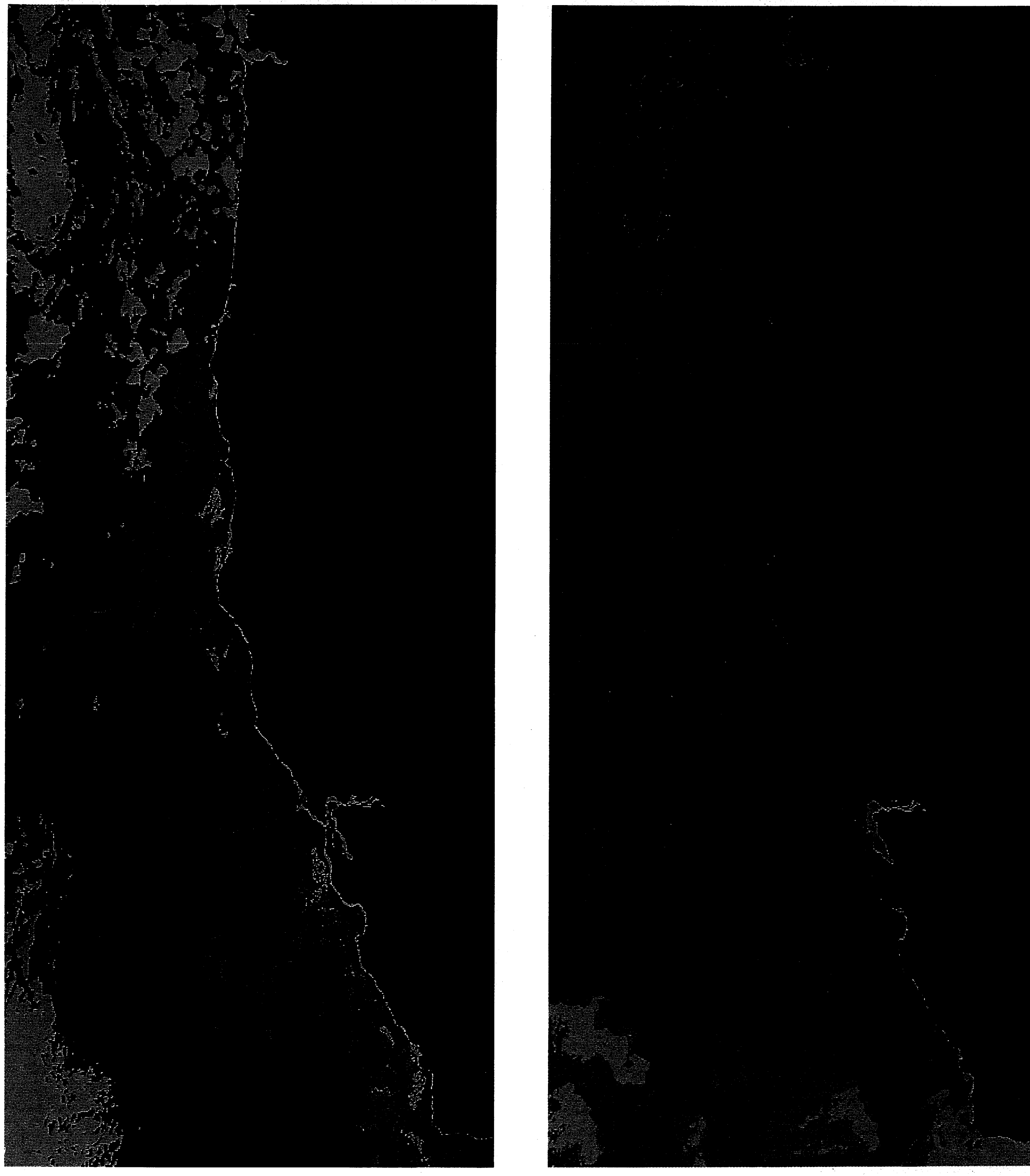


Plate No. 10 Coastal surface waters offshore, where there is an upwelling of cooler subsurface water, are among the most productive ocean regions for harvesting fish. Satellite ocean color measurements have been used successfully to map distribution of chlorophyll and other colored substances. These satellite images, taken 8 hours apart, represent phytoplankton chlorophyll pigment concentrations *(left)* (higher concentrations are shown in reds and yellows, lower in blues and greens) and west coast sea-surface temperature *(right)* (cooler temperatures are in violets and blues, warmer in yellows and reds). Images were derived from infrared temperature readings of the Advanced Very High Resolution Radiometer and from ocean color measurements of the Coastal Zone Color Scanner.

CREDIT: JET PROPULSION LABORATORY

Plate No. 12 This Thermal Infrared Multispectral Scanner (TIMS) image illustrates how multispectral imagery can be used to remotely discriminate different types of rock on the basis of their silica content. The bright blue areas at the top of the image are volcanic basalts, the purple area near the center of the image contains various metamorphic rocks, and the magenta area at the bottom is composed of sand dunes. This TIMS image was obtained in southern California and it has proven particularly useful for differentiating various types of rocks that outcrop in the metamorphic terrain in the center of the image.
CREDIT: JET PROPULSION LABORATORY

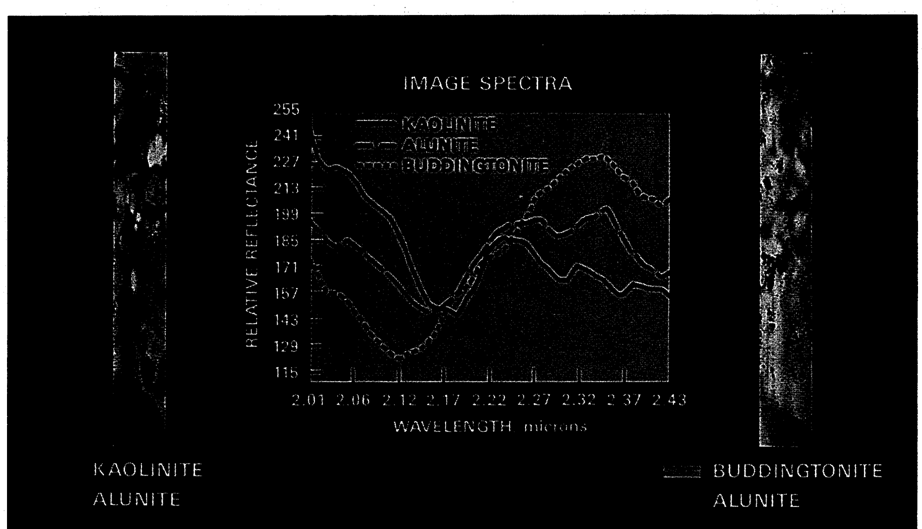


Plate No. 11 Many narrow, contiguous spectral bands of the Airborne Imaging Spectrometer can reflect minerals on the ground. Accurate mineral maps can be produced in seconds from such images and their derived reflectance curves.
CREDIT: JET PROPULSION LABORATORY

Applications Objectives

5

The issue of land degradation is crucial to human survival; it is a problem affecting vast geographic areas and the food supply of millions of people.

Important, concrete advances can be made relatively quickly in the practical use of remotely sensed data. To demonstrate the usefulness of remotely sensed data over the near term, the Working Group selected topics in the four major sectors serving the user community: renewable resources, nonrenewable resources, ocean, and atmosphere. Of the myriad possible questions that could be addressed by global data, the Working Group decided to focus plans on five objectives: land degradation; global forest distribution and local forest production/yield estimates; occurrence of strategic mineral resources; ocean hindcast, nowcast, forecast system; and atmosphere (climate) four-dimensional (time) data assimilation. Selection of these objectives was based on the following criteria:

- Size of the geographic area affected
- Populations affected
- Economic importance
- Importance to human survival
- Political acceptability
- Probability of achieving results

Each topic requires the collection of data, development of algorithms and models, in situ testing and demonstration, and transfer to users. All make use of both existing remote-sensing instruments and of experimental new instruments planned to be in use by the mid-1990s. By 1996, the outcome of these projects—the tested data, algorithms, and models—will be available to users as modules in the planned, evolving information system. The architecture of the integrated Applications Information System is based on the configuration of the four subsystems that will result from the demonstrations.

An applications objective is defined as a statement of what is to be accomplished in terms of quantity, quality, and time. In the operational definition adopted by the Working Group, *quantity* refers to how much of what is to be done, *quality* means within what parameters or caveats, and *time* refers to when the applications objective will be accomplished.

RENEWABLE / NONRENEWABLE RESOURCES

With regard to potential renewable resource problems, land degradation and forests were selected as the two major categories in which specific, quantifiable issues of practical value would be addressed. These two areas were selected on the basis of the criteria presented above.

Land Degradation Objective

Define and validate by 1995 new information systems that support global mapping of arable land degradation every 5 years, showing losses due to salinization, desertification, and erosion, with an accuracy to within 10 percent.

The issue of land degradation is crucial to human survival; it is a problem affecting vast geographic areas and the food supply of millions of people. Land degradation

The ever-increasing demand for arable land requires intelligent and economic resource management. Remotely sensed data . . . can facilitate the monitoring [etc.] of land degradation and thereby lead to improved methods of resource management.

can be attributed to several processes: strip mining, acid rain deposition, flooding, erosion (due to wind and water), salinization, urbanization, and desertification, among others.

For purposes of this report, arable land is defined as all lands that can support and sustain the production of food, fiber, and energy resources. As the population expands, the need increases for arable, productive land. However, along with population expansion comes a decrease in land areas. The ever-increasing demand for arable land requires intelligent and economic resource management. Improved knowledge is needed of what and where arable lands exist and how these lands can be preserved and developed to provide optimum production capability. Above all, the recovery time for seriously degraded land is decades, if not longer, and recovery can be enormously expensive.

Within the past 10 years, the lack of new arable lands—coupled with the loss of arable land through land degradation, specifically through salinization, desertification, and wind and water erosion—has caught the attention of land improvement managers and policymakers worldwide. Millions of dollars are being spent to develop water resource projects for land improvement and to fight the problems of salinity, desertification, and other forms of land degradation.

The amount of soil taken out of production by salinization is increasing each year. Globally, it is estimated that salt-affected regions of the Earth exceed 950 million hectares. More than one-third of these areas are located in the Western Hemisphere, mostly in the United States, Mexico, Peru, and Argentina. Failure to maintain an adequate balance between the amount of water used and soil drainage, which affects water quality, may allow an excess of soluble salts or exchangeable sodium to accumulate in the soil profile, causing soils to become unproductive. It is well known that many ancient civilizations (e.g., Mesopotamia) were destroyed by salinization of fertile areas, which caused the formation of deserts.

Desertification has been linked to the following causes: population pressure, including activities associated with increased population such as excessive harvesting of the land; changing animal grazing patterns or intense overgrazing; regional and global climatic changes of natural origin or induced by human activities; and inundation by drifting sand.

It has been estimated that erosion causes two pounds of soil to be redistributed for every pound of maize grown. Not all of this soil is lost; it gets redistributed. For example, in Missouri about 20 percent of the soil is eroded into the waterways; the remaining 80 percent is redistributed on the fields and associated lower land areas, causing sediment-related changes. However, the total accumulated losses from that 20 percent and the associated reduction in productive arable land are enormous. The extent of this erosion phenomenon and its causes must be understood if an expanding population is to be supported.

Erosion not only reduces arable land, but causes siltation in rivers and lakes and subsequently reduces water quality. Soil erosion is primarily generated by strong winds blowing over dry soils or by rainfall over sloping lands. The parameters affecting soil loss and their relationships are presently represented in the universal soil loss equation for water erosion and by the wind erosion equation. Extreme examples of erosion are the Midwest dust bowl of the 1930s and the current situation in the Nepal mountains. Current models or algorithms, such as the universal soil loss equation, are either quite site-specific or lack precision and need to be improved. An improved soil loss equation to estimate water erosion in different geographic areas currently is being tested by Department of Agriculture soil scientists and engineers.

Remotely sensed data such as Landsat Thematic Mapper (TM) and SPOT Panchromatic and Multispectral Scanner (PN and XS) data, combined with spectral, spatial, field, and laboratory measurements, can facilitate the monitoring, quantifying, and forecasting of land degradation and thereby lead to improved methods of resource management. Development of an improved information system will allow resource managers to quantify land degradation accurately and precisely. The risk of failure is small, because spaceborne systems are well suited to monitoring land cover and quantifying its areal extent.

Measurements and Model Requirements: Land Degradation

In defining measurements and model requirements, the Working Group selected three causes of arable land degradation from those listed in the previous section: salinization, desertification, and erosion. Salinization has been chosen to illustrate the process of development, demonstration, and technology transfer needed to meet each objective, as well as the development of an information system. However, for each type of land degradation discussed earlier, the development of techniques and testing needs to be repeated to fully achieve the objective for overall land degradation applications.

Figure 5-1 depicts the overall process envisioned for achieving and updating the land degradation monitoring and quantification objective. As can be seen, users must be involved as early as possible to define realistic and reasonable requirements. Once the requirements are established, the process will involve defining test sites; developing algorithms for identifying, delineating, and quantifying degraded land; compiling data bases; and formulating models of degradation processes. Users should be included in the development of demonstration projects that will encompass gradually larger regions, as well as in the development of tools and techniques. As new technologies and new mandated requirements are developed, the process will need to be repeated. This is the reason for a feedback, return, or iterative "loop" in Figure 5-1.

Figure 5-1
Generic Development Process for Land Degradation Objective

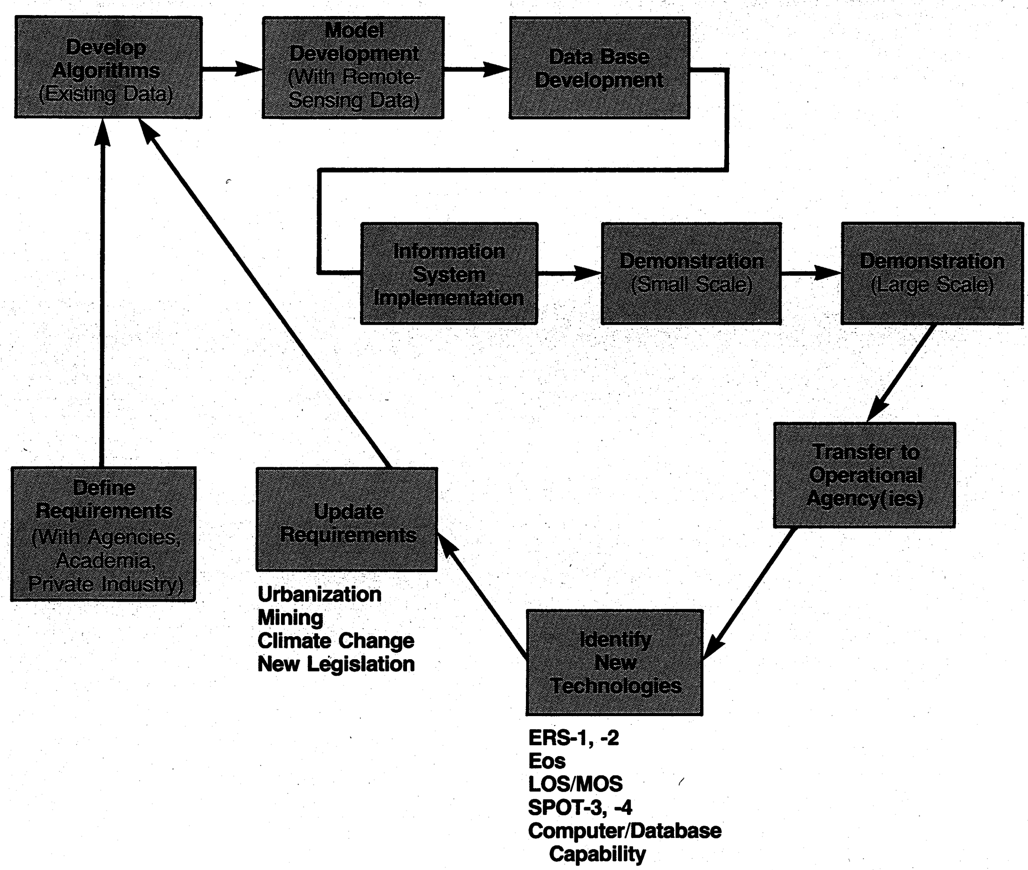


Figure 5-2 illustrates how the land degradation objective would be achieved in the next decade. It illustrates one sample degradation process and should be repeated for each process included in the decadal demonstration. To achieve a substantive and convincing demonstration, the projected information system should include, in priority order, salinization, desertification, and erosion over the next decade.

Figure 5-2
More Specific Developmental Steps for Land Degradation Objective

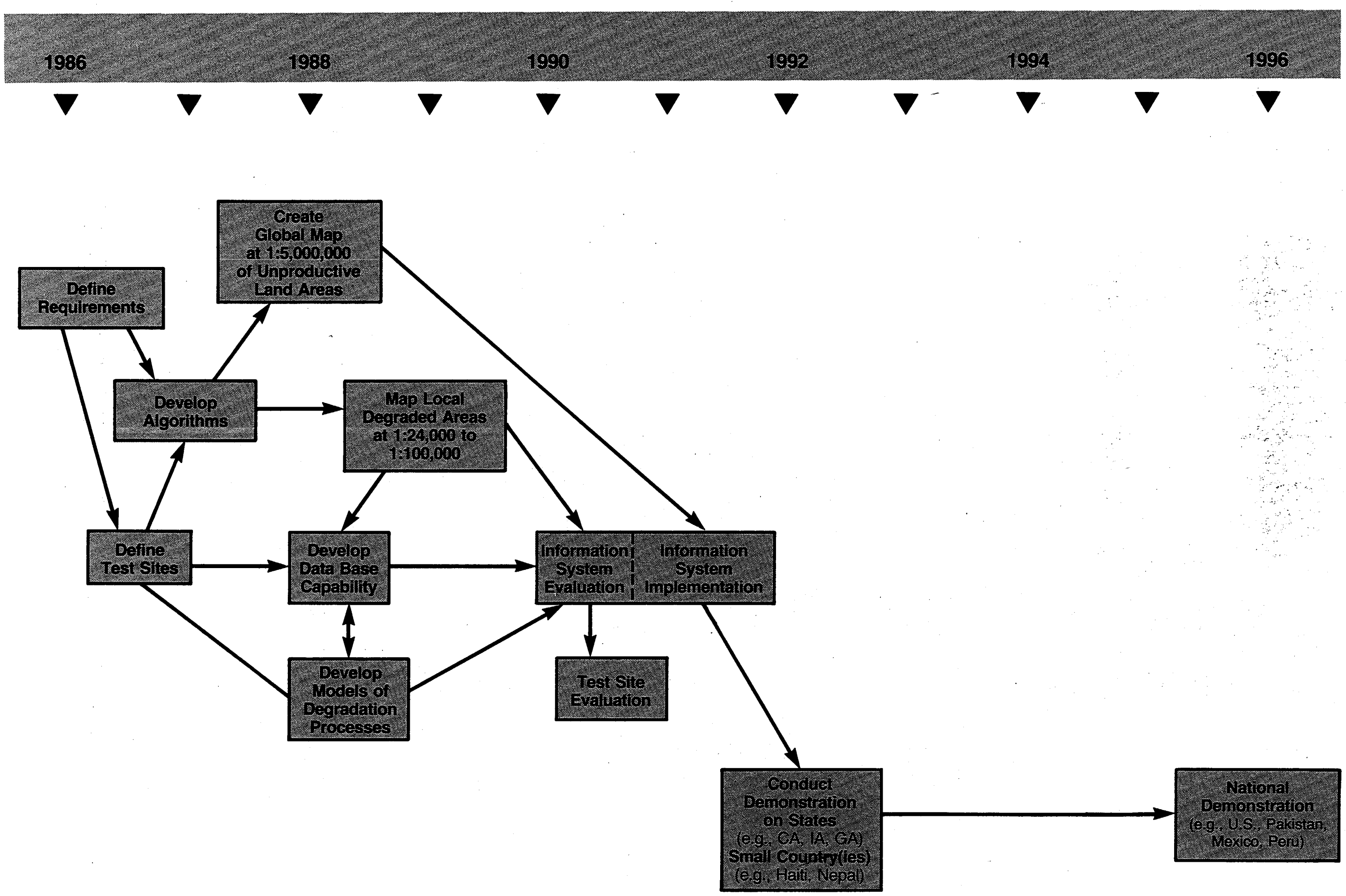


Figure 5-3, a milestone chart, more precisely depicts the timing of needed steps over the next decade. As its major points, this figure shows an information system, to be exercised at the test site level, that pulls together remote-sensing maps of degraded land, a data base including remotely sensed data and in situ data, and models that make use of these data. The test site exercising of the information system(s) should occur in 1990-1991. This information system(s), depending on whether one, two, or three of the processes were included in the development activity, would be exercised on a large region basis (e.g., a state or small nation) in the 1991-1993 period and on a national basis in the 1993-1995 period. In these latter stages, it will be imperative that the most effective and efficient use possible be made of existing information systems.

Table 5-1 is a compilation of data type, data volume, measurement or mapping accuracy, and model development requirements. The principal remotely sensed data will come from the Landsat sensors (Multispectral Scanner [MSS], TM, and possibly a wide-field-of-view sensor on Landsat-6 and -7), SPOT sensors (again including a wide-swath multispectral instrument that may be available on SPOT-4), and the NOAA Advanced Very High Resolution Radiometer (AVHRR) and improvements of that sensor. Much auxiliary data will be involved, and it is envisioned that a directory/cataloging capability will exist in the 1993-1995 time frame. The directory will be supported by a network that allows the required data to be acquired, stored, or compiled, permitting the Land Degradation Information System(s) to monitor, quantify, and forecast the evolution of arable land status on a national level.

Figure 5-3
Milestone Schedule for Land Degradation Objective

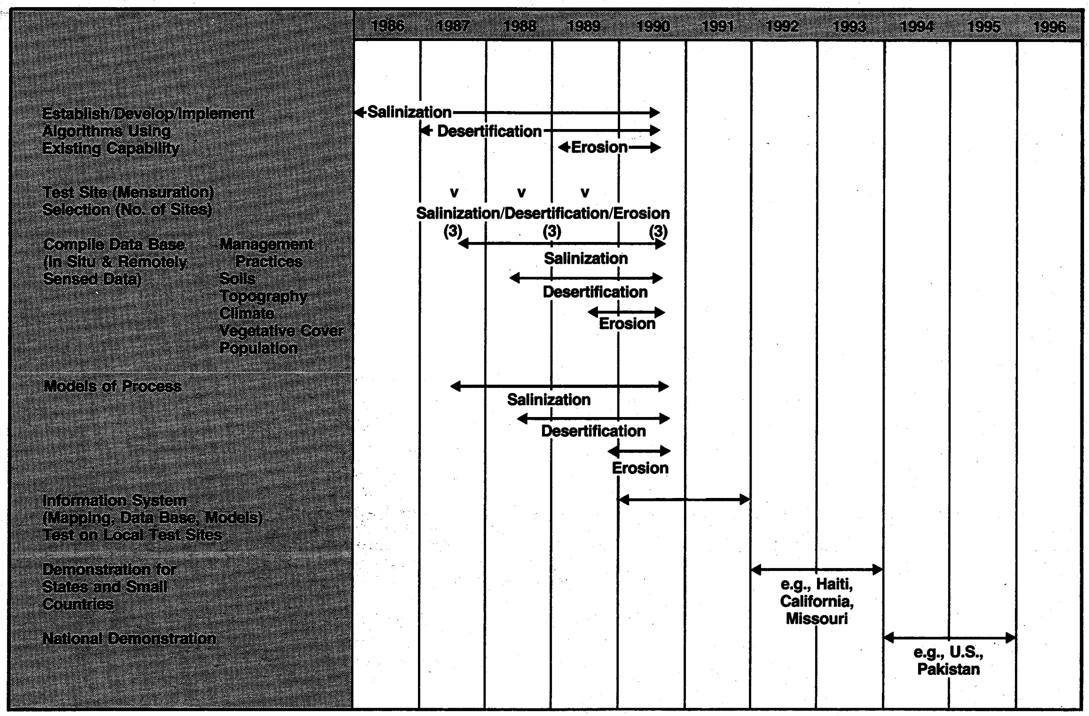


Table 5-1
Some Requirements for Measurements and Modeling for Selected Land Degradation Processes

Requirements	Desertification	Salinity	Erosion
Satellite Measurements			
Satellites	AVHRR, Landsat, SPOT, (ERS-1)	Landsat, SPOT	Landsat, SPOT, ERS-1
Map Accuracy	1:5,000,000; 1:100,000; 1:24,000	1:100,000; 1:24,000	1:100,000; 1:24,000
Resolution	Determined by sensors	Determined by sensors	Determined by sensors
Timing	Spring	Late spring/late summer	Late spring
Frequency	Annual	Annual	Annual
Algorithms/Models	Loss of vegetation Seasonal changes Change detection Climate conditions/change	Loss of vegetation Soil brightness (albedo) Irrigated: saline water Water table fluctuation	Decrease of vegetation Univeral Soil Loss Eq. USLE Vegetation vs. topography
Validate Data (other data)	Higher resolution imagery with ground observations	Higher resolution imagery with ground observations Soil samples	Higher resolution imagery with ground observations Physical measurements
Computational Data	10^8 Pixels -10^{10} 10-15 variables	10^8 Pixels -10^{10} 10-15 variables	10^9 Pixels -10^{12} 10-15 variables
Hardware Requirements	Landsat -6 & -7, SPOT, ERS-1	Landsat -6 & -7, SPOT	Landsat-6 & -7, SPOT, ERS-1
Auxiliary Data	Climate conditions/changes Population—human & animal Soil types Wind erosion Overgrazing Cultural practices Historical imagery	Water table depth Soil pH Electrical conductivity Irrigation practices Water quality Historical imagery	Soil Topography Vegetation cover Climate Historical imagery
Current Capability	Visual observation of loss of vegetation	Brown or patchy Low-quality vegetation	Sediment in rivers and lakes Gullies Slides
Desired Capability	Automate, quantify the areal extent Determine degree and intensity of desertification Predict and take corrective action	Provide early automated detection so corrective measures can be applied Monitor progress and success of restoration	Identify and assess degree of erosion in annotated procedures Provide maps and statistical data for corrective structures or practices

It has been estimated that in the United States alone, the demand for wood products will increase threefold from 1970 to the year 2000.

User involvement and cooperation are essential to this process. NASA should not and cannot carry out this objective and process without user involvement. NASA can, at a minimum, keep user groups informed about the characteristics of new scientific information systems so that they can access these systems.

To complete the demonstration successfully, the cost and requirements for new resources must be carefully considered, particularly in the case of Federal agencies, where funding and personnel resources are typically fixed or can only be altered very slowly (e.g., on a 3- to 5-year interval. In essence the proposed information system should be assimilated into existing or already planned systems with as little disruption as possible. Little new technology is likely to be needed, but new or improved algorithms, models, and associated procedures will require effort and attention.

Forest Objective

Define and validate by 1995 new information systems that support global mapping of forested versus nonforested areas every 5 years at scales of 1:1,000,000 with 1 km accuracy, and local mapping of forest production and yield estimates every year at scales of 1:24,000. The local mapping will cover five 1,000-acre sample locations in the United States. It will provide 20 percent improvement in accuracy over current techniques for conifer, uplands deciduous, wetlands deciduous, and mixed conifer-deciduous stands of trees.

The role of forests in our environment needs to be better understood. Forests affect the distribution of precipitation, local and regional energy balances, atmospheric cycling of carbon and nitrogen, and disposition of water through loss by evapotranspiration and surface runoff. Forests therefore have an extensive impact on a range of key environmental elements—soil, weather, temperature, wildlife, erosion, and cleansing of carbon dioxide from the atmosphere. These impacts must be more precisely and accurately quantified so that they can guide and be persuasive in a multitude of forest resource management decisions; these decisions usually involve questions with large economic and social implications.

On a pragmatic level, forest yields matter for human survival and quality of life. Wood is a significant worldwide source of both fiber and fuel; it is a source of energy that can be renewed. In short, extensive and accurate information systems must be implemented to meet these challenges.

Important central questions concerning forest environments can be answered by using current remotely sensed data. Existing data sources are capable of providing global maps that distinguish forested from nonforested areas with considerably greater accuracy than is available by other currently used techniques. Global mapping over two seasons—summer and winter—when repeated at 3- to 5-year intervals, would provide a standard for measuring and monitoring change in global forest distribution. This global mapping and updating from space would highlight, for the first time, world forest distribution and how it is changing.

Such global data would also support the local mapping of vegetation production and yield estimates, an issue of concern to U.S. operational groups such as the Department of Agriculture Forest Service, local governments, national and international forest industries, and the scientific community.

The ability to make improved local production estimates, at different latitudes, of forest yield by canopy type and density would have enormous significance not only for the U.S. timber industry, but for a wide range of users globally. Among the most prominent would be U.S. operational groups, local governments, nationally and internationally based timber companies, and the scientific community concerned with the quality of the environment.

Accurate estimates of forest yields, quantifiable by type and density of canopy, would be of major scientific and practical importance. On both a local and global scale, we need to understand and evaluate the influences of changing forest vegetation on other environmental properties. For example, massive deforestation of the Amazon Basin in Brazil is causing local climatic changes and may be having significant influences on global climate patterns. Making global forest comparisons at planned intervals will help determine the rate at which forest growth is changing and affecting other environmental properties.

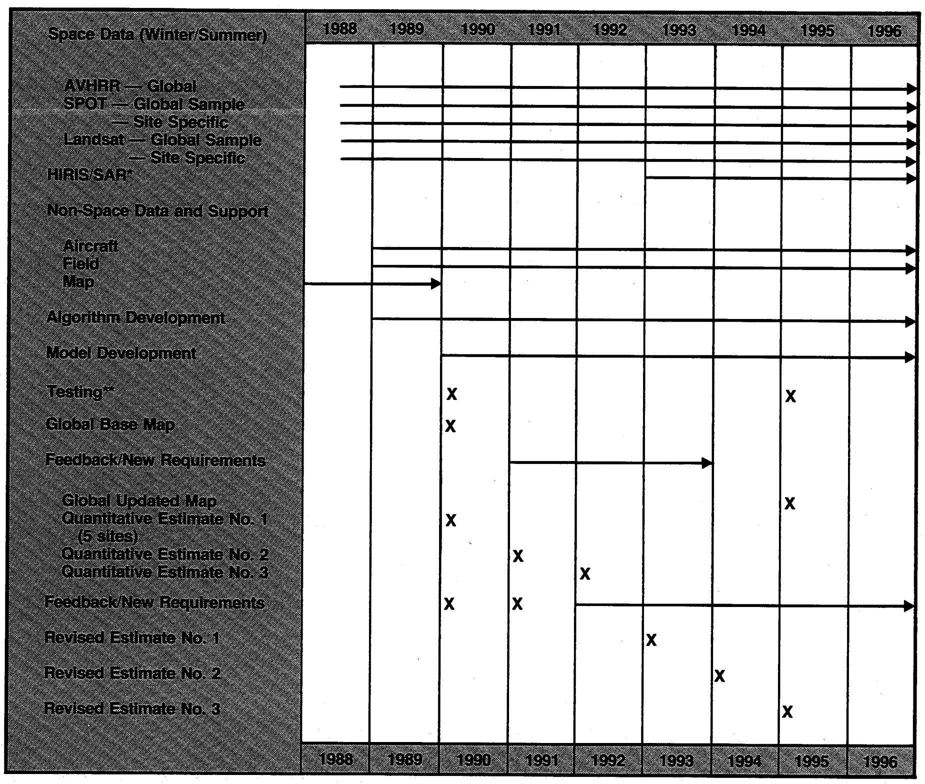
Wood and wood products production are areas of major economic importance for the United States. It has been estimated that, in the United States alone, the demand for wood products will increase threefold from 1970 to the year 2000. At the same time, available land for producing timber is decreasing at an alarming rate. Urban expansion and clearing of lands for uses other than forest regrowth head the list of reasons for this decline. The challenge for forest managers worldwide is to meet this increased demand in the face of a shrinking land base. This can be done only through more efficient use of lands and a greater interest by forest management worldwide. Improved yield estimates would support U.S. timber companies as a strong and competitive industry, as well as improve the planning capabilities directed at timber management and growth.

To the degree possible, selective forest cover maps representing global forest conditions will be digitized and entered into the information base.

Measurement and Model Requirements: Forests

Annual forest type mapping and information pertaining to the volume, density, and productivity of local forest conditions is a logical site-specific subset of a global forest distribution mapping program. Both result in products from common data sources and support each other in an updating and maintenance situation. Many of the spaceborne and nonspaceborne data sources are already in place; however, the means to access and utilize them for the most part are not. What will be required are the definition and development of algorithms for cataloging and retrieval. A general timeline for achieving the stated objective is outlined in Figure 5-4.

Figure 5-4
Milestone Schedule for Forest Objective



*High Resolution Imaging Spectrometer and Synthetic Aperture Radar
** Testing consists of verification by sample data sets gathered from ground level sites.

Data Acquisition and Measurements

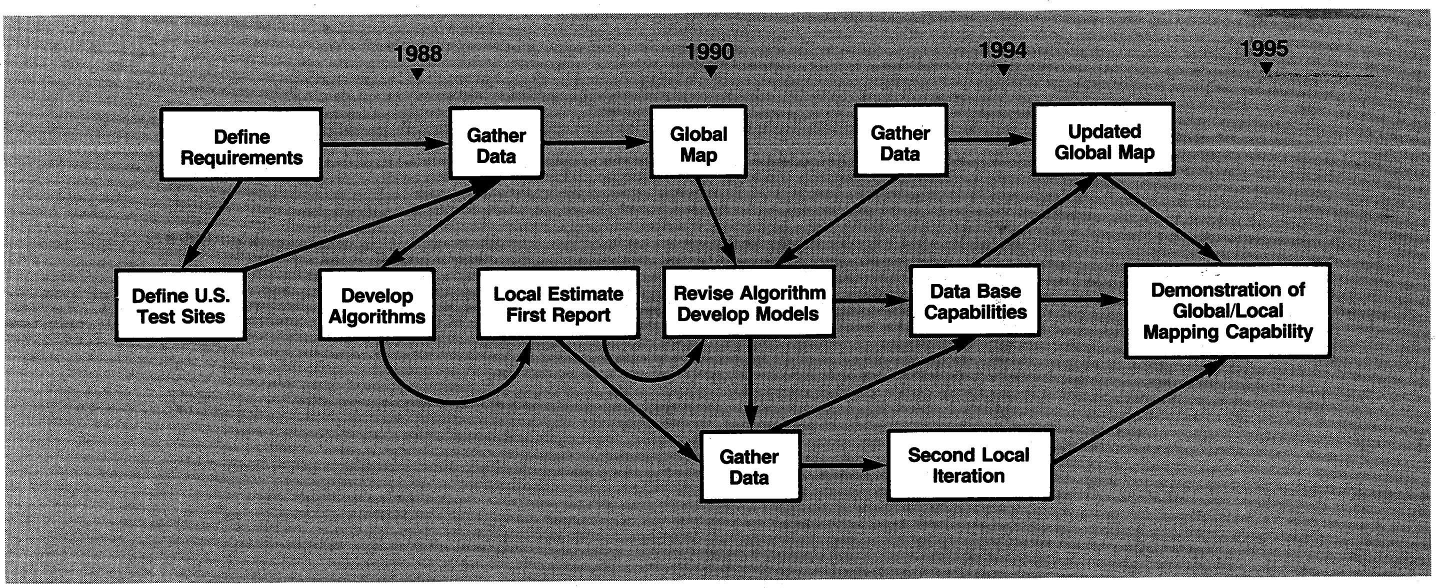
The global map objective will provide, among other things, a basic index for site-specific investigations with regard to forest cover. For such broad area averages, AVHRR will be used because of cost, speed, and the level of detail required; (viz., forest/nonforest). To the degree possible, selective forest cover maps representing global forest conditions will be digitized and entered into the information base. It should be recognized, however, that such a global map has never been generated at the level of accuracy required and that existing maps are not all-inclusive nor current with regard to the present situation. Low polar-orbiting satellites, such as Landsat and SPOT, will be used to subsample the scene and to verify and correct the cover maps. In support of this subsampling activity, the High Resolution Infrared Imaging Spectrometer (HIRIS) and Synthetic Aperture Radar (SAR) systems should be employed when brought on line in the early 1990s.

In addition to forest cover training and definition, maps will be required to overlay geopolitical boundaries and to provide suitable annotation where available. Gridded

AVHRR, Landsat, and SPOT references can be provided along with locations of the individual sample scenes. Such an integrated data base will provide an important reference catalog of worldwide site-specific locations. Quick-look capabilities would provide scene quality and location verification. For such a global forest map to be viable, provisions for updating and maintaining this map in a 5-year cycle must be provided. The initial map, therefore, must be as precise and accurate as possible, commensurate with the resolution of the data.

Space data collection platforms are in orbit for AVHRR, Landsat, and SPOT, and acquisition can begin in 1988 upon definition of requirements. The general flow of activity is illustrated in Figure 5-5. Two sets of data are required: leaf on, leaf off (summer/ winter), and considering regional cloud difficulties, 2 years are provided to acquire the basic imagery data set. Concurrently, representative map bases will be gathered, digitized, and entered into a geographic data base.

Figure 5-5
Major Development Steps for Forest Objective



Concurrent with the global map generation and the associated archive and catalog activity, data will be collected on site-specific areas for quantification of volume, density, and productivity parameters. Unlike the global forest cover map, the site-specific work will be more algorithm/model than data oriented. These algorithms/models will be developed around the relationships and correlations existing among volumetric, crown density, and productive growing sites, and spectral responses and classification results. These must be developed within the confines of categorical and standard statistical bounds so that proper statements of precision and accuracy can be applied to the results.

To achieve maximum control in establishing these procedures, five sites—1,000 acres each—will be selected from the temperate forests of the United States. Data will be collected by Landsat or SPOT over all five sites annually for 3 years, providing replication in both time and space. Modifications and changes resulting from the initial measurements will be incorporated, and another 3-year annual replication of data will be gathered to provide revised estimates. Collateral with satellite data collection, selected aerial photographs and supporting field measurements will be made to test the procedure. Required field data collection is expected to be a systematic sample from fixed radius plots that will be documented and entered into the geographical data base.

Because of the wide number of species associations in the United States alone, any procedures will necessarily be generic. As such, only broad species groups will be used: conifer, uplands deciduous, lowlands deciduous, and mixed conifer-deciduous. Geographic referencing is essential for quantitative estimates. Mapping scales of 1:24,000 will be required. However, the base cartographic input could well be from the 1:100,000 map series of the U.S. Geological Survey. Volume estimates and yield predictions are stated in terms of quantities (cords, board feet, cubic feet, or tons) per unit area. Equally critical is the proper assignment of area to those unit area values to arrive at accurate totals.

Algorithm and Model Development

Ground-based algorithms and models pertaining to growth and yield are available in many places. In those areas where they are not available, it will still be considered a ground-based activity involving ground measurement and historical data.

The model development needed should allow identification of measurements from space. This would include leaf index and canopy closure models. In addition, much work must be accomplished in the area of information management technology, including merging of disparate data bases, categories, access, and retrieval. What is needed (and is not necessarily proprietary information except for several exceptions) is the methodology for information extraction. Table 5-2, although not all-inclusive, suggests the distribution of effort.

The operational information system that will evolve for land degradation projects should effectively serve the multidisciplinary needs of government agencies and the private sector.

Table 5-2
Participants in Forest Model Algorithm Development

Activity	Developer	
Algorithm/Model/ Procedure	NASA/University	Commercial User/University
Leaf Area	X	
Crown Closure/Basal Area	X	
Stored Development	X	
Productivity	X	X
Growth		X
Yield		X
Volume		X
Statistical Design		X
Biomass	X	
Econometrics	X	X*
Management	X	X*
GIS	X	X*

* In these cases, NASA is its own user and will need forestry expertise to carry out its mission.

Forestry applications do not require a large and complex information system. Strong academic support to the forest service industry is needed. Further, in some areas where no proprietary questions exist, combined efforts by a triumvirate of NASA, universities, and the private sector could be very effective.

The establishment of reliable quantitative, predictive techniques, along with the organizing and managing of associated data bases, are prerequisite steps toward the development of viable expert systems in forestry.

Operational System Requirements: Land Degradation and Forests

The operational information system that will evolve for land degradation projects should effectively serve the multidisciplinary needs of government agencies and the private sector. The requirements of these groups will be similar in terms of format and accuracy but different in the areas of data cost, delivery time, and quality. Users should be involved in all phases of the project to ensure understanding and commitment.

Operationally, a single production facility should suffice to map global forest distribution. The users will be distributed among national governments and the private sector, but they will use the final product without being involved in production.

For wood volume estimation, users will be the same as for global forest mapping. However, users will be working in their own individual areas. A large number of production facilities will be privately owned and will maintain proprietary information. The information systems of these production facilities will be integrated with the overall organization management information systems. These systems will be significantly different from each other because of the different needs and management structures of the user organizations.

User requirements. The operational system for land degradation should facilitate data delivery in different scales and formats. Scales as large as 1:24,000 may be required, and scales as small as 1:5,000,000 may be quite useful for gaining a national, continental, or global estimate. About 300 Landsat TM scenes will be required for the United States; about 2,000 scenes will be needed globally.

For global forest distribution, not more than 200 AVHRR partial scenes per year will be required, half in summer and half in winter. In addition, 20 TM or SPOT scenes, 1 summer and 1 winter, will be required over the 10 sample sites; these would establish forest versus nonforest signatures to be used in classifying data in the AHVRR scenes. Beginning in the mid-1990s, these scenes should be augmented by annual equivalent amounts of HIRIS and SAR data to be used for the same purpose. When available at each of these sample sites, descriptions based on ground visual observations of the vegetative cover types will be required. Digitized maps containing topography, climate, and political boundaries at a scale of 1:5,000,000 will be required for merging with the satellite data.

For wood volume estimation at five selected local U.S. sites, one winter and one summer, one TM or SPOT scene from each site will be required. Beginning in 1992, equivalent amounts of HIRIS and SAR data should be added if available. Twice yearly, summer and winter, Airborne Imaging Spectrometer (AIS) data will be required over a 1 square mile subsite in each of the five sites for signature generation and for algorithm and model development. For each site, topographic maps with 5-foot contours will be required as well as mean climate data.

Data delivery. A reasonable time frame of about 30 days would be judged adequate for timely data delivery. Available data would include temporal data reflecting the periodic seasonal changes inherent to erosion, salinity encroachment, and the advance of desertification.

Ground measurements of wood volume will be required annually for assessing the accuracies of the remote-sensing methods. Forest distribution and wood volume estimates will be made only once per year.

Computational resources. For land degradation projects, long lifetime data storage will be required. The computational facility should include the use of VAX and micro-VAX computers, minicomputers, floppy disks, and the contemplated new generation of optical disks. Information systems must be compatible with microcomputers so that individuals and small users can access the information system and use it effectively and economically. Neither the volumes of data, the model complexities, nor the classification/data processing requirements call for large mainframe computer facilities.

For the global forest distribution and the wood volume estimation activities, the computerized capability will need to be the equivalent of a VAX 11/780 with such suitable accoutrements as work stations, digitizing equipment, light tables, photo lab facilities, and a map printer.

Communication. The deployment of a network of data base systems would enhance the speed and quality of data acquisition and transmission when speed is required. Data collection platforms may also be part of the network. NASA's experience with the Program Support Communication Network and the Space Physics Analysis Network, which have both a high rate and speed of data delivery, should be built upon to strengthen the operational communication network. The Pilot Land Data System experience is and will be instructive.

Ancillary data sources. In addition to remotely sensed satellite data, the land degradation information users will need data from other sources. For desertification applications, data are necessary on human and animal populations. Linkages to international relief organizations will provide estimates for areas where hard data are not available. Pointers to the locations of these estimates should be provided through the integrated information system. Such organizations as the World Resources Institute already have established contacts with other organizations working on land degradation tasks; these organizations should be consulted in establishing data base contacts.

Data will be required on climate conditions and changes, topography, soil types and characteristics, and diverse cultural methods of animal production. In addition, historical images and photography of the study areas will be most valuable for interpreting some causality factors.

Training. No unusual training needs beyond those presently available are foreseen, except for the possible need to introduce users to new data types as advanced sensors become available. The information system should be PC compatible, and training should be directed toward those systems. Background will be required in remote sensing, data processing, and management information systems that are appropriate to the users' types of business. This expertise is presently available.

Cost. For land degradation, the cost for acquiring and analyzing the Landsat scenes is estimated at $1.5 million every 5 years for U.S. studies and $10 million for global studies. The potential near-real-time availability of spaceborne remotely sensed data will affect the efficiency of commercial and government operations, which should have an impact on operations costs.

For global forest mapping, the production installation cost estimate is approximately $10 million with an annual operating cost of between $1 and $5 million. Part of this sum will be recoverable from map sales, but a portion would need to be public monies expended for public purposes. Some of the needed amount may come from funds presently appropriated for public purposes by other, less-efficient methods.

In the case of wood volume estimation by many individual user organizations, the remote-sensing-related part of the operation will be submerged in the organizations' overall data and information management systems. Each system may differ substantially from the others; therefore, it may not be possible to extract from these an average acquisition and operating cost for the wood volume estimating activities alone.

To ensure that the applications objectives are successfully met, it is crucial that users participate with NASA in every step of the demonstration project.

Demonstration Projects: Land Degradation and Forests

To ensure that the applications objectives are successfully met, it is crucial that users participate with NASA in every step of the demonstration project. Although no standard method can be proposed to reach these objectives, it is highly desirable that both NASA and the user maintain a high level of technological compatibility throughout the implementation of the demonstration project. The following reasons justify the need to achieve compatible technology:

- Procedures used to generate information must not exceed the capability of the user's infrastructure to produce similar information when NASA's involvement terminates.
- Adoption of the technology by the user in an operational mode will be based essentially on the user's ability to produce technically and commercially useful products as a result of having participated with NASA in the design and execution of the demonstration project.

The principal users will be government (e.g., U.S. Department of Agriculture Forest Service, Soil Conservation Service, and U.S. Agency for International Development) and private commercial organizations. Other important users will be the World Bank, the InterAmerican Development Bank, the African and Asian Development Banks, U.N. Food and Agricultural Organization, and other international and regional agencies.

Technical success and operational success are two criteria for measuring a successful demonstration project. The vitality and dynamism with which the user organization continues to make use of the technical processes, in the absence of NASA's valuable inputs, would be the key indicator of achievement.

A forestry demonstration project aimed at producing a global map would be carried out annually over 6 consecutive years. Erosion measurement may be required every 2 to 4 years, a general assessment of erosion every 5 years.

A global land degradation map would be produced by 1990 at a scale of 1:5,000,000 to delineate areas without vegetation, and annually thereafter, a map of sample sites of 1:24,000 to 1:100,000 would be generated. Such maps would be updated annually for 5 consecutive years to test the stability of the results and to pinpoint significant changes.

Technology Transfer Process: Land Degradation and Forests

Technology transfer is a complex and sometimes difficult process having technical and nontechnical problems. The technical part of the process requires the involvement of all user organizations in all levels of the applications development and demonstration programs. The nontechnical programs frequently are more difficult. Public and commercial organizations will need to integrate remote-sensing systems with their overall management systems, and accommodations in both will be necessary.

The most effective steps NASA can take to encourage technology transfer is to involve potential users from the very beginning and to give them a serious voice in designing the experiments.

Both public and private organizations have needs for secrecy and for the withholding of certain proprietary information from public disclosure. Commercial organizations need such secrecy to maintain their competitive economic positions. Public agencies need this for reasons of competition among nations, national security, and to avoid giving some private organizations unfair access to data not yet generally released . An example of the latter is the confidentiality accorded the U.S. Department of Agriculture's crop yield estimates prior to general release.

Land Degradation

In the case of the land degradation objective, the principal users of the information system developed will be government agencies at the Federal, State, regional, and local (e.g., an irrigation district) levels. These agencies will be supported by commercial entities that in many cases will contract with the government to provide land degradation studies or supporting data. The commercial entities, in turn, may want to use the information systems developed to study land degradation by remote sensing, or they may want to incorporate successful parts of information systems developed in a demonstration mode into their own existing data systems.

Given these realities, it should be understood that any information system, or portions thereof, will be adopted by users if it can be assimilated easily into their existing information systems with minimum disruption. Only in relatively rare cases where a highly probable large profit can be made, ready cash is available, or new funding can be identified, will it be either permissible or possible for users to make large changes in their systems and assume costs for equipment, new personnel, or heavy training expenses.

NASA, in developing any information system, should be cognizant of these conditions and the requirement for easy access to any NASA system developed to support related science efforts as well as access to demonstration systems developed for other agencies or applications.

NASA's primary role should be that of expeditor and facilitator of the transfer process. NASA should not develop an information system independently and then attempt to sell or give it to the user. This process rarely works in either the short or the long term.

In developing the land degradation information system, it seems essential that the Soil Conservation Service and Agriculture Research Service be involved. Because of the Soil Conservation Service's responsibility for the National Resource Inventory, the U.S. Department of Agriculture must endorse or be a part of this applications objective if it is to be an unqualified success.

Representative users involved in land degradation monitoring and quantification must be brought into the applications systems development process at the earliest stages (e.g., conceptual and design phases) to ensure transferability and avoid failure both on a programmatic and on a technical basis. Many requirements and decisions must be made during these phases about test sites, models to be enhanced or developed, and data base design.

Forests

The problems in transferring technologies to user agencies and organizations are somewhat different in global forest distribution mapping, compared with those in wood volume estimation. This is because of the importance of proprietary information in the latter and the natural differences in the areas involved. The two areas are therefore discussed separately.

Wood volume estimation technologies are of interest to private organizations and to governmental agencies. Wood volume estimates will be performed in the existing data and information systems of the individual organizations and agencies. As such, these systems will be devoted to all functions of the organization, including wood volume estimation. Furthermore, because of differences among institutions, it is unlikely that wood volume estimations will be performed in the same way.

Therefore, NASA should design wood volume estimation data systems that user organizations will be able to use; namely data and catalogs to dispersed data archives. Each agency and organization will undoubtedly design its own procedures and equipment suites to mesh with its overall data and information system.

Within each country, there probably will be little resistance by governmental agencies to sharing data, information results, algorithms, models, and other methods among sister agencies and private organizations. However, there will be many instances of strong resistance to such sharing with non-nationals.

There will be strong resistance to sharing data, methods, and results among commercial organizations within a country, thus causing resistance to using shared facilities. Commercial organizations will be influenced by complexity and sophistication versus cost trade-offs, and in many instances each will be interested in a restricted area.

Global forest distribution mapping will almost certainly be done by international governmental organizations, individual Federal agencies, and government-supported scientific organizations, as well as industry associations.

In both global forest mapping and wood volume estimation, the most effective steps NASA can take to encourage technology transfer is to involve potential users from the very beginning and to give them a serious voice in designing the experiments. Furthermore, during this phase, nonthreatening test areas should be selected, that is, government-owned sites.

Once a demonstration has been completed, the NASA role would seem to be fairly restricted. Each organization will make its individual decision about whether to adopt operationally the techniques demonstrated and whether to provide access to catalogs of the contents of relevant data archives. NASA could provide a service to Federal user agencies in providing access to space-derived data. For commercial organizations, the desirability of NASA as a central source of access to space-derived data is not so clear. If NASA makes information publicly available regarding which commercial organizations are buying what data, the firms may wish to deal directly with EOSAT, SPOT, and other data providers to ensure confidentiality. Third party organizations such as the value-added service industry will be participating in the technology transfer.

The nature of the selected applications will place a minimal demand on rapid access to [remotely sensed] data or exchange of data among investigators; that is, each test site will be distinctly separate, with independent activities.

Information System Requirements: Land Degradation and Forests

The renewable resources subsystem will need to facilitate the measurement and understanding of land surface problems, particularly those having site-specific and multitemporal characteristics. These specific applications programs do not require real-time data, but it should be noted that later programs may. They do require repetitive coverage, with examination of the data within the context of multiple physical and biological parameters. They further require the use of data analysis techniques using geographic information systems to manipulate multiple layers of information and data.

Users

The user community will include the commercial, academic, and government sectors, and perhaps international participants. Each user is expected to be an expert in a particular discipline and to develop a specific, quantifiable demonstration and test program. Each will select a test site, assemble necessary data bases, and develop and exercise appropriate algorithms and models to derive information required for the application demonstration. Users may be those at existing, well-established institutions, as well as new users selected by the process described in Section 7. It is estimated that the program will involve 30 to 40 such demonstrations.

Each user group will be associated with a site ranging in size from several square kilometers to 30,000 square kilometers, except for one case of low-resolution global mapping of the world's forests at a scale of 1:5,000,000.

Data

Remotely sensed data. These applications experiments are designed to use data from Landsat, SPOT, NOAA satellites (AVHRR), Marine Observation Satellite, ESA Earth Remote-Sensing Satellite, and HIRIS (if available). It is estimated that because of the limited size of the demonstration sites, the initial volume of data will be approximately 10^9 bytes per year. As the program develops into the operational phase, the data volume will approach 10^{11} bytes per year.

The nature of the selected applications will place a minimal demand on rapid access to data or exchange of data among investigators; that is, each test site will be distinctly separate, with independent activities. Thus, it is visualized that each of the users will assimilate and manipulate their own digital data bases, with most of the data coming from existing, distributed data sources. The data will need to be geocoded (i.e., each information element such as a picture element of an image or map will have an assigned geographic address). The data can be distributed to the users on magnetic tapes or optical disks, because the phenomena under observation are slowly varying, the measurement cycles being annual.

Validation data. To assess adequately the performance of algorithms and models for generating the desired information, the quality of the input data and the information derived must be ascertained. This process will require validation data. For readily accessible sites, validation will consist of field observations and measurements with the assistance of higher resolution imagery and/or maps. In inaccessible areas, multistage sampling techniques will be required, preferably using some quantitative data from public or private sources regarding the state of the phenomena under investigation.

For test sites in the United States, 10 to 100 aircraft flight-line miles of data possibly will be needed over each site, using NASA's high-resolution airborne imaging spectrometer. It is anticipated that most of the specially collected validation data will be of interest only to the immediately associated investigators and need not be archived centrally.

Auxiliary data. For most applications, satellite imagery by itself does not yield quantitatively useful information, with change detection being a major exception. Thus, the application demonstration will require merging the satellite imagery with other data (whenever available), such as climatic conditions and maps showing topography, soil, geology, vegetation species, and land use. The data must be geocoded and digitized. Initially, a total volume of about 10^9 bytes will be needed by the users. By 1995, large area demonstrations may require approximately 10^{11} bytes of geocoded data. These data can be stored and transported on magnetic tapes and/or optical disks.

Standards for Quality Assessment and Documentation

Each collected data set must have associated with it documentation regarding calibration, data quality and accuracy, instrument and other acquisition specifications, and data processing history. For the comparison and assimilation of multiple data sets, geocoded radiance measurements should be described in absolute terms.

All data entering the system must be geocoded in raster or vector format, as appropriate. Data headers must identify geographic location, date, and origin of data.

The subsystem will require a directory that can provide pointers to data, facilities, researchers, analysis capabilities, and other resources. Catalogs must provide more detailed information about models, algorithms, and data sets, including location, time and date, cloud conditions, attributes, origin, quality, accuracy, and history of data. The level of catalog detail should permit users to determine whether any categories are of interest to them. Browse files are needed for all types of data. Directories and catalogs should be accessible via electronic query.

Algorithms for data processing and models to estimate physical phenomena will be a central focus of the research and development effort; the generally useful algorithms and models should be included in the catalog. Generally accepted standard algorithms and models should be available to the users. These include land degradation and canopy reflectance models, and calibration, classification, and change-detection algorithms. Some users will have algorithms and models that are experimental or proprietary; these will not be generally available.

VAX and micro-VAX type computers will be required by the users. Existing geographic information systems, image analysis, and statistical software will be used as technological starting points. Some adaptation and improvements probably will be necessary.

Some relatively minor facilities will be required for field observations and measurements. These may include up to 20 data collection platforms.

Recommendations

Such issues as the needs of the applications community, the relationship between NASA and potential users of remotely sensed data, and factors which might hinder or help the successful implementation of the proposed plan were considered in developing the following recommendations:

- Applications programs should be initiated in two priority areas: land degradation and forests.
- NASA should involve potential user organizations in the planning and execution of the Applications Research Program.
- NASA should give maximum attention to the development of models and algorithms in the Applications Research Program.
- Access should be provided to existing archives of space data for applications users and a catalog of archive contents should be provided pertaining to space and other related data.
- In designing information access mechanisms, NASA should recognize the likelihood that each operational user will design and implement its own information system tailored to the user's individual needs.

• NASA should start these programs in FY 1988 using currently existing data and associated capabilities.

Nonrenewable Resources Objective

Develop and validate new data management systems and information extraction techniques by 1993 that are needed for globally evaluating potential occurrences of strategic, nonrenewable resources at a 1:50,000 scale. These systems and techniques are expected to be used on a routine basis in the latter 1990s following the launch of the NASA/NOAA Polar Platform. To achieve this objective, it is recommended that a prototype information system be developed to demonstrate how remotely sensed data could be used in combination with conventional types of geological/geophysical data to evaluate the potential occurrence of chromium, cobalt, manganese, and platinum group metals at selected test sites distributed throughout the world.

The industrial base of the western world is critically dependent on the availability of raw materials used in the manufacture of high-technology products. The manufacture of such products as jet engines, high-performance aircraft, spacecraft, launch vehicles, electro-optical instruments, and computers is dependent on the availability of low-cost, high-strength, high-temperature, corrosion-resistant alloys and semiconductor materials. Fabrication of these products is, in turn, dependent on low-cost availability of the strategic materials highlighted in Figure 5-6.

Several factors are increasing the vulnerability of western world countries to the reduced supply of these strategic commodities: (1) political unrest in Africa, South America, and Central America; (2) industrial expansion in Europe, Asia, and the Pacific; and (3) emerging industrialization of developing countries. Although most of the mineral commodities listed in Figure 5-6 are known to exist in the United States, at least one-half do not exist in sufficient concentrations to be economically mined and processed into raw materials.

In 1985, the U.S. Congress Office of Technology Assessment (OTA) published a report entitled, "Strategic Materials: Technologies for Reducing U.S. Import Vulnerability." This report lists three tiers of mineral commodities according to how critical they are for U.S. industry and national security. The first tier consists of four commodities—chromium, cobalt, manganese, and platinum group materials—that are almost exclusively produced in South Africa, Zaire, or the Soviet Union.

The 1985 OTA report recommends development of new technologies and geological models that can be used to evaluate alternative sources of these commodities globally. Furthermore, the report acknowledges that NASA and the Department of Commerce have an important role to play in such a research program because of their respective missions: to conduct global Earth observations and to monitor the productivity of the U.S. economy.

The following are other Federal agencies that will benefit directly from improved information on the availability of strategic materials:

- Department of Interior
  —U.S. Geological Survey
  —U.S. Bureau of Mines
- U.S. Department of State
- U.S. Department of Defense
- National intelligence and security agencies

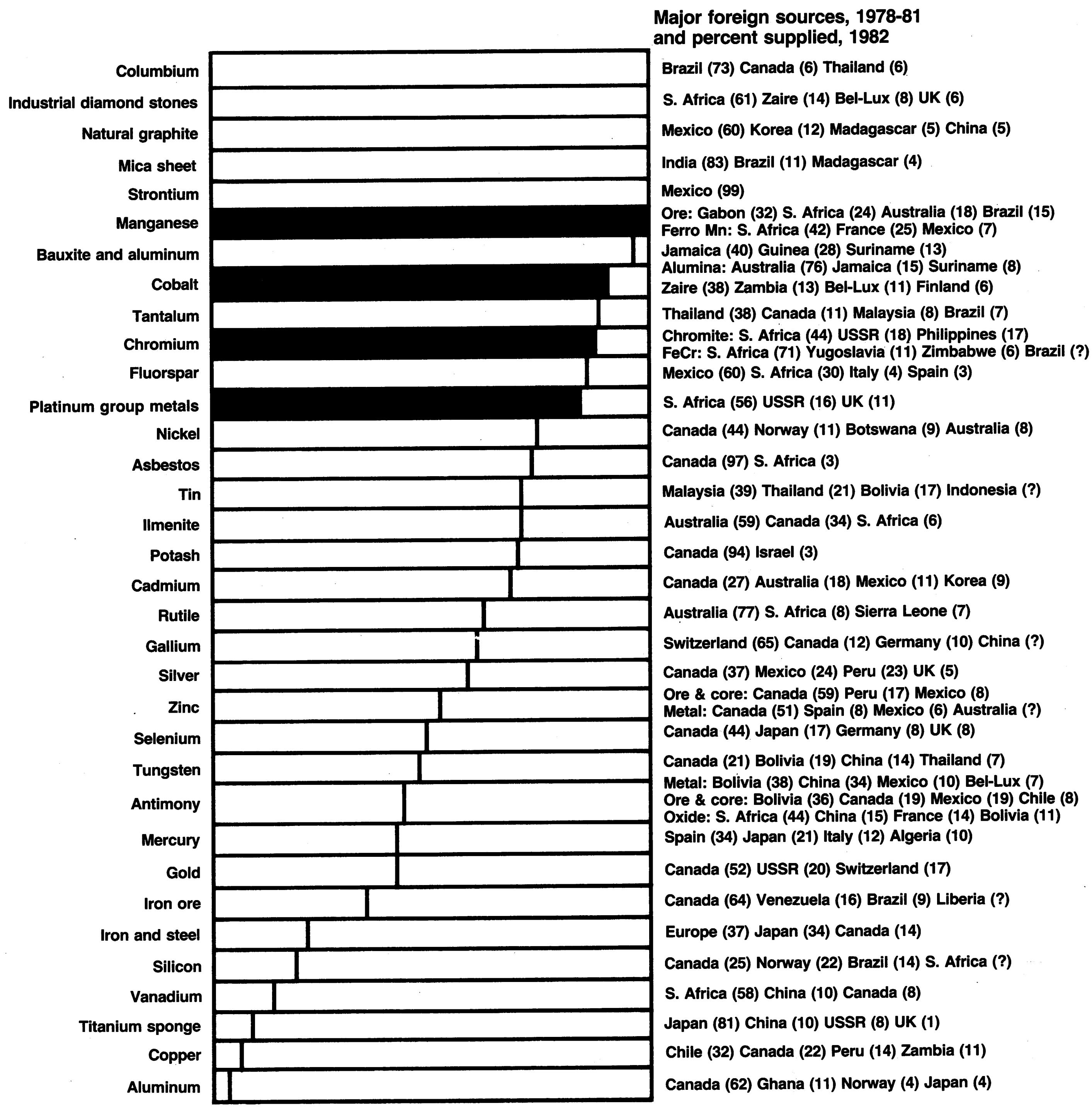
Improved techniques for strategic materials assessment ultimately will provide tools needed by private industry to find and develop alternative sources of supply. Technologies and techniques developed in the conduct of this applications research program will lead to improved methods of resource assessment that can also be applied to the search for base and precious metals, oil and gas, coal, and uranium. These techniques also could be adapted for a wide variety of geological engineering applications, such as identifying sites for waste disposal and dam construction and defining environmental baseline conditions to establish requirements for land reclamation.

Implementation of the proposed demonstration project would produce significant benefits for NASA, the geological community, and the nation. From NASA's perspective, the anticipated results would provide a concrete demonstration of how remotely sensed data can be used for nonrenewable resource evaluation in the 1990s. Many of the data sets required by the project would be acquired by experimental aircraft sensors that are precursors of comparable instruments to be placed on the NASA/NOAA Polar Platform. Consequently, the results of the project would serve to expand the community of geologists that could make effective use of Polar Platform data in the latter 1990s.

Although most of the mineral commodities listed . . . are known to exist in the United States, at least one-half do not exist in sufficient concentrations to be economically mined and processed into raw materials.

From the perspective of the geological community, the demonstration project would provide new and unique insights into the occurrence and genesis of certain types of mineral deposits. More importantly, it would provide a unique demonstration of how to manipulate and merge large quantities of digital data. Geologists commonly archive and transfer information in the form of paper maps and film transparencies. This project would give selected members of the geological community a unique opportunity to access and manipulate a wide variety of digital data

Figure 5-6
Net Import Reliance as a Percent of Consumption, 1982



NOTES: Net import reliance is figured as percent of apparent consumption, except for rutile, for which net import reliance is figured as percent of reported consumption.
Net imports — imports - exports - adjustments for government and industry stock changes.
Apparent consumption — U.S. primary and secondary production - net imports.

SOURCE: U.S. Department of the Interior, Bureau of Mines bases in a highly interactive fashion. The results of the project would likely stimulate far wider future use of information system technology within the geological community.

Finally, the results of the demonstration project should enhance the effectiveness and efficiency of strategic mineral exploration in many parts of the world. This will reduce the nation's vulnerability to interruptions in the supply of strategic materials that are required by the industrial economy of the United States and other western nations.

[Some] of the most critical limitations in our ability to apply remotely sensed data to geological problems arise from limitations in the models used to obtain radiometric and landscape information from raw radiometric data.

Measurement and Model Requirements: Nonrenewable Resources

Nonrenewable resource assessment is a two-step process. Step one involves the collection and analysis of observations from a variety of sources to develop a three-dimensional model of crustal composition and structure within a particular area. Step two involves comparing this model with similar models of areas containing known deposits of specific mineral commodities.

The geological characteristics of areas of known production are synthesized to produce a set of predictive models commonly referred to as commodity occurrence models. The degree to which the three-dimensional crustal model of the prospect area matches a particular commodity occurrence model is a predictive measure of the likelihood of encountering that commodity within the prospect area.

The role of remote-sensing observations in strategic material evaluation is conceptually illustrated in Figure 5-7, which displays the various steps involved in performing, interpreting, and applying remote-sensing measurements to the problem of strategic mineral assessment.

At their most fundamental level, remote-sensing observations are simply measurements of the number of photons arriving at the entrance aperture of a sensor system per unit time, wavelength band, and ground area. The sensor collects these photons and quantifies the number present, normally by using a grey scale to characterize variations in the intensity of radiation emanating from different portions of the Earth's surface. These radiometric data are displayed in a two-dimensional format as a picture or image of the Earth's surface. Analysis of radiometric patterns found in single picture elements (pixels) results in the identification of spectral signatures for landscape cover materials. Models must be employed to relate such signatures to the presence and abundance of specific surface materials. Analysis of spatial radiometric patterns in groups of pixels can provide additional information concerning the nature of materials exposed at the Earth's surface.

Geologists employ a series of models to extract various types of landscape information from the radiometric information contained within a remotely sensed image. The two major categories of landscape information that can be obtained through this analysis are surface topography (i.e., landforms and drainage) and surface cover (i.e., nature and distribution of surface materials). Landscape information is interpreted to obtain geological information concerning the types of rocks that are present, the sequences in which they occur, the extent to which they are folded or faulted, and so forth. Many other types of measurement techniques, such as geophysical surveys, field mapping, and rock/soil geochemical analysis, can provide useful geological information for purposes of mineral assessment.

Figure 5-7 illustrates the hierarchy of models employed in actually using remote-sensing observations for purposes of nonrenewable resource evaluation. Models required for generating radiometric data from radiometric measurements are developed by sensor engineers to meet the design requirements of individual sensor systems. Models required to extract geological information from landscape information have largely been developed by photogeologists. Continued research in both of these areas is needed. However, some of the most critical limitations in our ability to apply remotely sensed data to geological problems arise from limitations in the models used to obtain radiometric and landscape information from raw radiometric data. These limitations are discussed in greater detail in a subsequent section.

Remote-sensing measurement requirements for strategic mineral evaluation are summarized in Figure 5-8 and discussed below. Figure 5-8 illustrates the relevant types of landscape information that can be extracted from remote-sensing surveys performed in different spectral regions. Regions of interest include the visible-near infrared/shortwave infrared (VNIR/SWIR) extending from wavelengths of 0.4 to 2.5 microns; thermal infrared (TIR), specifically the 8 to 12 and 3 to 54 micron regions; and microwave, specifically multipolarization, multidepression angle measurements performed at 1 to 100 cm wavelengths. The following sections describe specific measurement requirements.

Applicability of Remote-Sensing Techniques

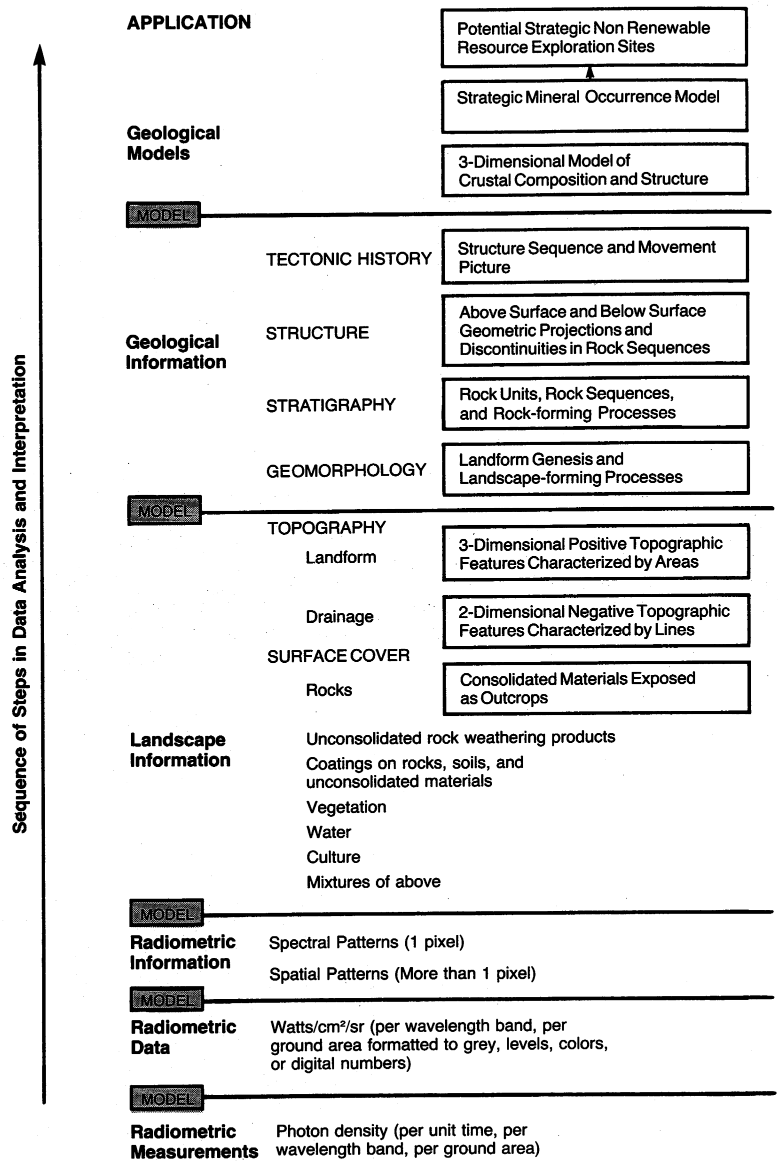
Chrome-bearing minerals are commonly found in ophiolite complexes, which are pieces of the lower crust and upper mantle that have been exposed as a consequence of plate tectonic processes. Ophiolite complexes contain ultramafic rock assemblages ranging in composition from peridotite to eclogite and basalt. Chrome-bearing minerals may occur as pods in previously subducted oceanic crust. These minerals are also commonly encountered in layered igneous complexes (e.g., the Stillwater and Skaergaard complexes). In all cases, ultramafic silicates (olivine) are present in moderate abundance. Olivine has a low degree of tetrahedral coordination (polymerization) and therefore has a diagnostic thermal emission feature (reststrahlen band) that allows the mineral to be uniquely discriminated in the 8- to 14-micron portion of the electromagnetic spectrum. In addition, ultramafic rocks weather in tropical-to-temperate environmnets to produce latosols (in some cases laterites), which only support limited vegetative growth. Many areas where ultramafic rocks are thought to occur are remote and inaccessible regions. Conventional exploration techniques are less effective and quite costly in such areas. Remote-sensing techniques hold greater promise for defining mineral potential in these frontier exploration regions.

Cobalt-bearing minerals commonly occur in association with igneous hydrothermal systems characterized by rocks containing abundant quartz and feldspars, but calcite, hydroxyl-bearing minerals (clays), and iron oxides often are present as rock alteration products. A spectral library of materials containing cobalt does not exist, but cobalt does have unique spectral properties when combined with calcite. Narrow-band imaging in the visible and reflected infrared should be useful in delineating potential areas where cobalt might be present.

Platinum-group metals commonly occur in ophiolites and layered igneous complexes, and the techniques described for chromite assessment would probably be applicable. An important aspect of this research would be to document the unique geological attributes associated with platinum group metals and chromite, which may enable discrimination of these two commodities.

Manganese-bearing rocks commonly occur in association with iron oxides in land areas. Manganese nodules on the sea floor are a potential source of supply, but the large capital costs of extracting nodules from the sea floor have limited development of that technology. Remote-sensing attributes of manganese-bearing minerals and associated minerals are understood, but little is known about geological attributes of terrains that may indicate economic accumulations of manganese. This, again, is an area where basic geological research must be conducted.

Figure 5-7
Use of Models in Applying Remote-Sensing Observations to Nonrenewable Resource Assessment



Resolution: Spatial, Spectral, and Radiometric

In the VNIR/SWIR portion of the spectrum, spatial resolution of 10 to 15 m for panchromatic data and 20 to 30 m for multispectral data is required to obtain surface topographic information with a +/− 10 to 30 m horizontal precision and a +/− 10 m vertical precision. Spacial resolution in the TIR will be dictated by radiometric constraints. The desired spatial resolution in the TIR is the smallest instantaneous field of view that can be used to detect variations in surface emittance above natural background levels. In the microwave region, a 20 to 30 m resolution with reasonable signal-to-noise levels is required.

Within the VNIR/SWIR, discrimination of various mineral species will require spectral resolutions of 5 to 10 nm. In the TIR, spectral bandwidths of 500 nm are required for mineral discrimination. For microwave sensors, existing X, C, and L band systems (3, 5, and 30 cm, respectively) are adequate.

Radiometric resolution required for geological applications are a NE$\Delta\rho$ of 0.1 percent (noise equivalent reflectance difference of 0.1 percent of total reflectance) for the VNIR/SWIR; NEΔT (noise equivalent temperature difference) of 0.3 K in the TIR; and a NEΔR (noise equivalent radiance difference) of 0.5 dB in the microwave portion of the spectrum.

Figure 5-8
Relationship Between Measurement and Information Requirements For Nonrenewable Resource Evaluation

Geological Information: Tectonic History	Crustal Structure	Stratigraphy	Geomorphology	Landscape Information	SPECTRAL REGION: VIS NIR SWIR (0.4-2.5 microns)	TIR (8.0-12.0 microns) (3.0-5.0 microns)	MW (Multiangle 1-10cm)
A	A	A	A	Topography • Drainage • Landforms	±10m Vertical Precision ±10-30m Horizontal Precision		±10m Vertical Precision ±10-30m Horizontal Precision
B	B	A	C	Surface Cover (Geological Materials)	Iron Oxides Iron Sulphates Clays Carbonates	Silicates Carbonates	Roughness Dielectric Contrasts
C	C	B	B	Surface Cover (Vegetation)	Density Community Boundaries Condition	Density Community Boundaries Condition	Density Community Boundaries Condition

A - Major Contribution
B - Moderate Contribution
C - Minor Contribution

Specific types of landscape information that can be extracted from different types of remote-sensing observations and their relationship to geological information requirements for nonrenewable resource evaluation

MEASUREMENT REQUIREMENTS IN DIFFERENT SPECTRAL REGIONS

VIS NIR SWIR	TIR	MW	Measurement Requirements
10-15m Panchromatic 20-30m Multispectral	Best Available Given Spectral & Radiometric Constraints	20-30m	SPATIAL RESOLUTION
5-10nm	500nm	X, C, L Band (3, 5, 30cm)	SPECTRAL RESOLUTION
Seasonal	Diurnal/ Seasonal	Seasonal	TIMING
Simultaneity highly desirable			
NE$\Delta\rho$ =0.1%	NEΔT =0.3K	NEΔR =0.5db	RADIOMETRIC RESOLUTION

*NOTE: Shaded areas have critical requirement for additional model development.

Timing

Probably the single most important comment on timing of data collection is the tremendous advantage of simultaneous data collection. Data collected at different times, under different atmospheric, solar, and seasonal conditions, are incompatible and therefore can be extremely detrimental to subsequent analysis and interpretation. For the TIR data, the collection of diurnal data is required for thermal inertia calculations useful in determining soil rock densities, as well as water content.

Relevant types of landscape information that can be extracted from remote-sensing surveys that meet these requirements are as follows.

Topography. To adequately define drainage and landform information, topographic information is required with a precision of +/- 10 m in the vertical dimension and +/- 10 to 30 m in the horizontal dimension.

Surface cover (geologic materials). Given the spectral measurement requirements defined above, it will be possible to identify and map several geologically significant mineral species using the VNIR/SWIR and TIR spectral data. These include iron oxides and sulfates, as well as some clay, carbonate, and silicate minerals. The greatest contribution of the microwave will be determining surface roughness and mapping contrasts in dielectric properties. The use of multispectral imagery for rock type discrimination is illustrated in Figure 5-9 (this image appears also as Plate No. 12, in the color plate section).

Table 5-3
Comparison of Current and Future Sensor Systems Applicable to Strategic Material Assessment

Sensor System	Operator	Status	Spectral Coverage	Spectral Resolution (No. of Bands)	Spatial Resolution	Comments
Thematic Mapper	Commercial/Earth Observation Satellite Co.	Currently Operational	VNIR/SWIR/TIR (0.4-12 microns)	6 VNIR bands 1 TIR band	30m 120m (Thermal)	Broad spatial and spectral imaging, suitable for limited broad category detection and mapping of limited materials
SPOT	Commercial/SPOT Image	Currently Operational	VNIR (0.5-0.9 microns)	Panchromatic/ Multispectral (3 bands)	10-20m	Suitable for stereoscopic imaging and landform analysis
Airborne Imaging Spectrometer	NASA/Jet Propulsion Laboratory	Currently Experimental	SWIR (1.2-2.4 microns)	128 bands (8-10μm each)	~10m	Detection and identification of materials with characteristic spectral signatures in short wavelength infrared
High Resolution Radiometer	Commercial/Geophysical Environmental Research	Currently Semioperational	VNIR/SWIR (0.4-2.5 microns)	576 bands	20m	Point data not applicable for mapping, useful for proof of concept for spectral mapping
Thermal Infrared Scanner	NASA/Jet Propulsion Laboratory	Under Development	TIR (8-12 microns)	6 bands	30m	Detection and mapping of numerous silicate mineral groups
Airborne Visible Infrared Imaging Spectrometer	NASA/Jet Propulsion Laboratory	Under Development	VNIR/SWIR (0.4-2.4 microns)	~228 bands	20m	Detection, identification, and mapping of numerous minerals and mineral components with characteristic spectral responses in the visible through shortwave infrared
Multivariant Imaging Microwave	NASA/Jet Propulsion Laboratory	Under Development	MW (3-10cm)	3 bands (3, 5, 30cm)	30m	General terrain mapping and texture mapping in multiple categories

tion program, because participation is envisioned as a major form of technology transfer.

The remaining tasks are largely self-explanatory. The first 2 years of the demonstration project (1988-1990) would be primarily devoted to identifying, acquiring, and georeferencing the various data sets to be used in evaluating mineral potential. The second 2-year period would be devoted to evaluating the likely occurrence of specific commodities at the individual test sites. If this prototype information system were made truly operational in the mid-1990s, and if the NASA/NOAA Polar Platform were launched in 1995, the project tasks shown on the milestone schedule during the period 1988-1990 could be performed routinely in a few months.

The principal factors that might limit the success of the proposed demonstration project are (1) the accessibility to foreign areas where strategic materials are known or suspected to occur and (2) the availability of ancillary data for prospective test sites. Well-known deposits of chromium, cobalt, manganese, and platinum group metals are primarily located in the Soviet Union, Zaire, and South America. Several of these deposits would provide useful training areas to validate the utility of remote-sensing methods for strategic mineral evaluation. However, political factors may limit our ability to obtain access to these areas. Other regions may be accessible, but conventional geological data such as gravity and magnetic surveys, soil maps, and topographic maps may be lacking for these areas. Cooperation with foreign institutions such as universities, government agencies, and private sector companies will be a prerequisite for the successful completion of the project.

Operational System Requirements: Nonrenewable Resources

In the area of nonrenewable resources, the user community will be composed of representatives from Federal agencies, universities, and private industry. The initial user community in 1989 should be about 20 groups, growing to a maximum of 100 user groups by 1993. Each of these user groups may be composed of from 1 to 10 individuals at each site or node.

The operational information system that will evolve from the prototype system developed during the demonstration project will be called on to provide data, information, algorithms, and related services to a far wider community of users. To meet the needs of this technically diverse and geographically dispersed community, the operational system must be fully functional under the following constraints:

User requirements. In the 1993 time period and beyond, we anticipate that local computational facilities with the basic capabilities of a VAX 11/780 or its equivalent will be available to the average system user. Furthermore, we anticipate that these types of facilities will be readily available to most investigators.

The operational information system that will evolve . . . will be called on to provide data, information, algorithms, and related services to a . . . wide community of users.

Strategic material potential will be evaluated at each test site using remotely sensed information and conventional forms of geological and geophysical data.

Data delivery. System users will routinely place orders for archived data sets that currently exist and "new" data sets that must be acquired by orbital sensors. Previously acquired data that reside within the information system should be routinely provided to a user within 1 week of receipt of a request. Data acquired in direct response to a new user request should be reduced and delivered within 2 weeks of receipt of order.

Communications. Telephone-based communication services are adequate for using the proposed information system to identify, locate, and order data sets required for specific projects. Telephone-based communications also will provide an adequate means of telemail communication among various system users. We anticipate that large data sets or extensive algorithms would be transmitted to users in the form of a magnetic tape or a comparable optical media product. However, if microwave or fiber optic communications are readily available to the user community by the mid-1990s, they could be employed for real-time transmission.

Ancillary data sources. Ancillary data sets other than remotely sensed imagery will obviously play a key role in mineral resource evaluation. Linkages to existing geological, geophysical, and geochemical data bases should be created wherever possible. High priority should be placed on adding the following data bases to the operational information system as soon as possible:

- Digital topographic data at all available scales
- Catalogs of existing geological and soils maps
- Digital gravity and magnetic survey data
- Geochemical surveys, including soil and stream sediment chemical analyses and airborne radiometric surveys
- Spectral libraries defining the spectral and radiometric properties of common surface materials on the basis of laboratory and field measurements
- Moderate Resolution Imaging Spectrometer, AVHRR, and Geostationary Operational Environmental Satellite data for purposes of applying atmospheric corrections to multispectral imagery
- American Petroleum Institute data base of well locations and well log data and comparable data bases for overseas areas, where available
- Digital cultural information

Training. The proposed information system should be well documented, menu driven, and user friendly with extensive embedded "help" information. Given these assumptions, little additional training would be required by potential users of the system.

Costs. The operational system is presently too poorly defined to specify exact costs for specific services. However, two general rules-of-thumb should be followed in defining user costs: (1) costs should be apportioned on the basis of the quality and quantity of the service provided (i.e., a catalog search should generally cost less than the purchase of a specific data set) and (2) costs should be defined on the basis of the customer's willingness to pay for specific services (i.e., costs should be "market driven").

Demonstration Projects: Nonrenewable Resources

The potential capabilities of the system will be demonstrated by conducting a series of pilot projects in areas containing known or suspected deposits of chromium, cobalt, manganese, and platinum group metals. Individual test sites will be on the order of 15 x 15 km to 50 x 50 km. These test sites will be situated in a variety of physical environments, such as tropical, temperate, and semiarid terrains, to validate the utility of the system for global strategic material evaluation.

Strategic material potential will be evaluated at each test site using remotely sensed information and conventional forms of geological and geophysical data. These various types of information will be used with geological models to predict the likelihood of encountering specific mineral commodities within the individual test site areas.

This demonstration project will be divided into two principal phases. The first phase will extend from 1988 to 1990. During this period, remotely sensed data will be collected over the test sites using existing orbital sensors (Landsat MSS and TM, and SPOT PN and XS) and experimental aircraft sensors (AVIRIS, TIMS, and airborne SAR). These data will be georeferenced to a common map projection and placed in a data base that will be available to all project investigators. Conventional forms of geological and geophysical data already available will be georeferenced in the same fashion and added to the data base. Finally, conventional forms of geological and geophysical data that are normally archived in the form of maps, such as photographic prints and transparencies, will be digitized, geocoded, and entered in the data base. This data base and the procedure developed for its use and manipulation will constitute a prototype of the information system that exploration geologists will require in the late 1990s for strategic material evaluation. In fact, the airborne sensor data placed in the data base will be very similar to data sets that will be routinely produced by sensor systems on the NASA/NOAA Polar Platform scheduled for launch in 1995.

NASA will play a critical role in providing the institutional and financial resources required to construct the prototype information system.

To be successful this demonstration project requires access to state-of-the-art sensor systems currently being developed by NASA; geological expertise and data sets that reside in the university community, private industry, and selected Federal agencies; and assured access to test site areas located in foreign countries. To meet these requirements, representatives from the following institutions should be invited to participate with NASA in the planning and implementation of the project:

- The university community, including NOAA-funded academic centers of excellence in land remote sensing
- Private industry, including major resource companies and value-added firms that provide exploration services
- Government agencies involved in resource assessment and development, such as the U.S. Geological Survey, the Bureau of Mines, and the Bureau of Land Reclamation; and National Science Foundation investigators conducting research in mineral genesis and emplacement
- Foreign universities, government agencies, and private sector companies actively involved in resource assessment and development

The purpose of this project is not actually to locate economic deposits of specific mineral commodities, but to demonstrate how remotely sensed data can be used on a routine basis for purposes of strategic material assessment. The key output of the project is the development of a data base management and information system that can effectively serve the broad community of geoscientists involved in strategic material evaluation in the latter 1990s. Consequently, the success of the project should be measured with respect to the efficiency and effectiveness of the prototype information system.

The recommendation is to impanel a group of industry participants during the initial stages of the project to develop a clear definition of success criteria from an applications perspective. Specific criteria that potentially could be used to gauge success include the following:

- The spatial scale at which mineral potential is characterized. Mineral potential maps prepared at global scales of 1:5,000,000 and local scales of 1:5,000 presently exist. (This project would produce comparable maps at an intermediate scale of 1:50,000, which are not commonly available.)
- The time required to perform the evaluation.
- The spatial correspondence between localities of high mineral potential predicted by the demonstration project and localities of known production (recognizing, however, that historical production patterns do not necessarily provide an accurate guide to actual mineral occurrence and distribution).

As indicated above, the initial phase of the project from 1988 to 1990 will be devoted largely to data collection and data base construction. The commodity evaluation phase of the project will be conducted from 1991 to 1993 during an approximate 18-month period. The results should be available to the geological applications community prior to the launch of the NASA/NOAA Polar Platform and will demonstrate how space-acquired data can be used for purposes of mineral evaluation at a scale of 1:50,000. These results are anticipated to stimulate expanded use of remotely sensed data supplied by Polar Platform payload instruments throughout all segments of the geological applications community.

Technology Transfer Process: Nonrenewable Resources

The ultimate "users" of the information system developed during the demonstration project will be private industry, selected Federal agencies, and selected members of the university community. The single most important consideration in transferring the technology to this large and diverse group is to involve representatives of each constituent group in all stages of the demonstration project. In our judgment, these users have no specialized technical needs that would limit their ability to employ the proposed information system. All potential users possess varying fundamental skills, relevant experience, and computational facilities required to exploit the proposed system. Barriers to use will arise primarily, and perhaps exclusively, from a

The subsystem initially will be site- and time-specific but eventually will become worldwide and multitemporal in scope.

lack of familiarity with the system's capabilities and limitations. These barriers can be avoided if representatives of each constituent group are involved in the demonstration project from the outset.

Secondary considerations in transferring the proposed information system to the applications community are resources and the dissemination of demonstration project results. NASA will play a critical role in providing the institutional and financial resources required to construct the prototype information system. Key institutional resources are the NASA aircraft and airborne sensor systems that will be used to conduct experimental remote-sensing surveys over domestic and foreign test sites during the demonstration project. Key financial resources are the funds required to sponsor research at selected universities and to build and operate the prototype information system. *NASA must be willing to disseminate the results of the demonstration project to the broadest spectrum of potential users in a timely fashion. These results must be fully documented in accessible technical literature, and they must be presented orally at major scientific meetings, seminars, and workshops. NASA must take an aggressive, proactive role in disseminating the results of the demonstration project to the potential user community.*

Value-added firms that provide exploration services to resource companies could play a major role in stimulating future use of the proposed system. These firms are anticipated to use the system to conduct a wide variety of studies related to resource assessment and development. The results of such studies could stimulate further use of the system on the part of their client companies. In our judgment, NASA should devote special effort to briefing value-added firms on the results of the demonstration project and it should provide special incentives for such companies to use the system when it is initially developed.

Information System Requirements: Nonrenewable Resources

The nonrenewable resources subsystem will allow users to have access to data and algorithms that will assist them in information processing and extraction. The subsystem initially will be site- and time-specific but eventually will become worldwide and multitemporal in scope. The first projects will not require real-time data, nor will they require rapid data transfer. These requirements can be envisioned easily for follow-on projects. All projects have a requirement for geocoding, that is, a geographic location being attached to all data points for easy reference and data overlay and integration. As for renewable resources, there is a need for analysis techniques using geographic information systems.

Data

All data must be digitized and geocoded to permit digital integration and overlay. A scale of 1:50,000 and a projection in the Universal Transverse Mercator grid system will be used unless other scales and projections are requested. Figure 5-10 graphically presents the time frame for the demonstration project data collection.

Remotely sensed data. The space-derived data are expected from Landsat, SPOT, and NOAA satellites. Airborne data from AVIRIS, TIMS, and SAR will be the principal data sets for the detailed analyses. AVIRIS data are expected to range from 10 to 15 gigabytes per test site.

Validation data. It is expected that ground and laboratory spectra will be collected for each site to validate and calibrate the space and aircraft data. Up to a few hundred data points would be collected for each site.

Auxiliary data. To reduce the ambiguity of the remotely sensed spectral data, all available auxiliary data should be cataloged and analyzed. It is expected that 100-500 megabytes of such auxiliary data will be collected.

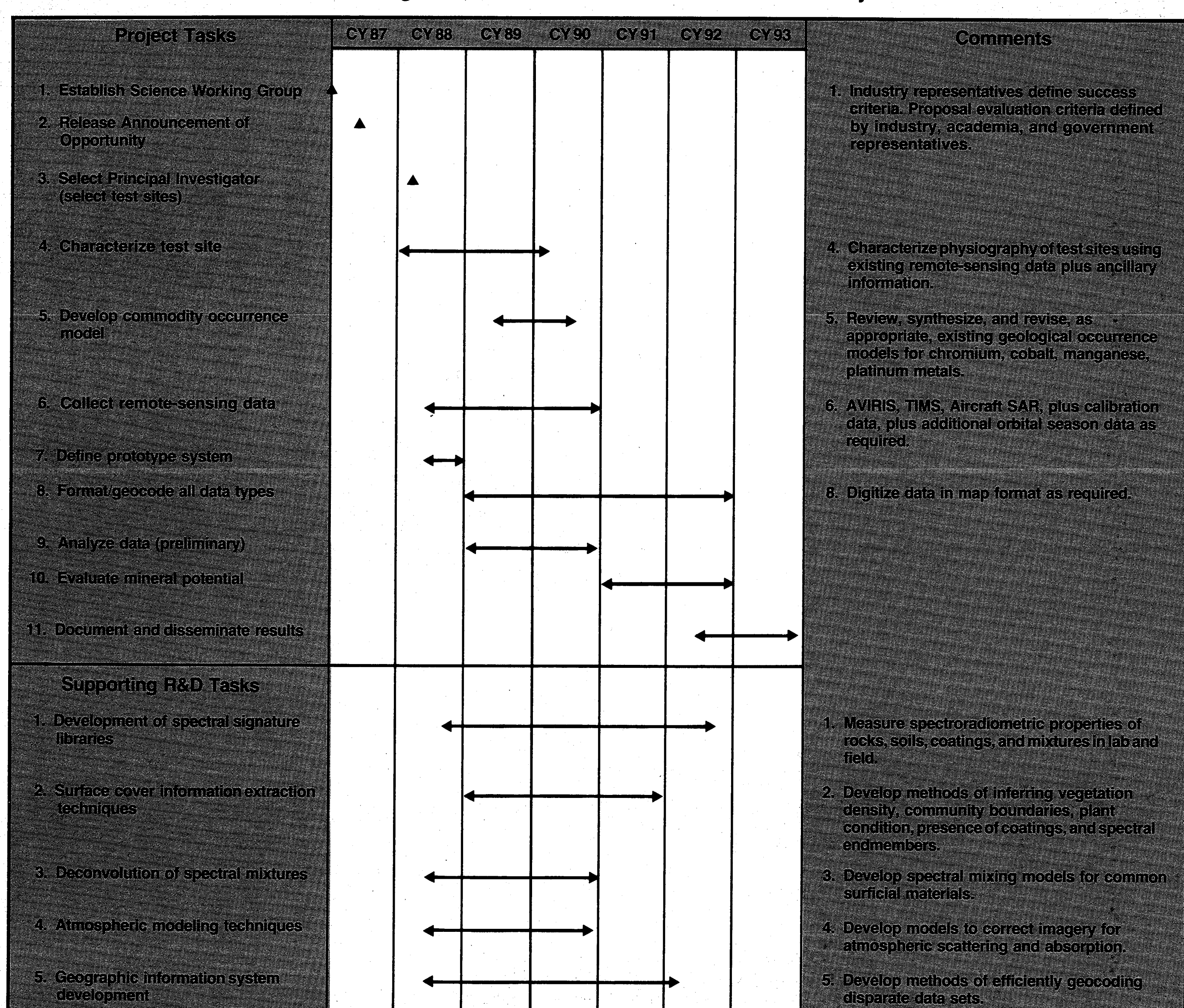
Standards for Quality Assessment and Documentation

The minimum documentation for each data set will be the instrument specifications, instrument calibrations and/or calibration algorithms, and the data processing history. For all data generated by the project and placed into the data base, there must also be adequate documentation to permit later uses by others.

Directories, catalogs, and browse files are required for all data types. Queries on multiple fields should be accessible through a support information network.

A group of generally accepted, standard algorithms and models should be available via the support information system for common usage. An example would be a set of algorithms for derivation of radiometric properties based on standard atmospheric models. The Department of Defense and some commercial users will have algorithms and models that are restricted or proprietary and, therefore, will not be available to other users.

Figure 5-10
Proposed Milestone Schedule for the Strategic Material Assessment Demonstration Project



Each user node will need at least a micro-VAX-sized facility for data processing. The support information system should utilize at least a VAX 11/780-size computer. Some users will require access to a supercomputer and/or an artificial intelligence (AI) machine for large models, AI development, and other computationally intensive operations.

No major new sensor hardware will be required beyond what is already on the NASA development schedule.

OCEAN AND ATMOSPHERE

Two applications objectives were identified in the area of ocean and atmosphere remote sensing. They are similar in proposing the design and development of research information systems that, through the use of numerical models, assimilate diverse data over time, provide gridded estimates (and accuracy measures) of key variables, and create certain types of forecasts.

Both of these objectives support and extend the NASA Eos and joint-agency Earth System Science programs. They focus NASA's scientific resources in the use of remotely sensed data and in the development of atmospheric and oceanic models leading toward the development of new information systems serving both research and applications. The objectives defined are achieved only as a result of space-based remotely sensed data.

Virtually all satellite remotely sensed and in situ data available in real time on the physical fields of the lower atmosphere and upper ocean will be used.

Ocean Objective

Define and validate by 1995 the design of an information system for an operational hindcast, nowcast, and short-term (up to 1 week) forecast system, with mesoscale resolution, for a number of oceanic and atmospheric planetary boundary layer physical variables.

The nowcast should be available hourly on a regional (ca. 1,000 km sq.) basis (2-km grid size) and daily on a global basis (100-km grid size), with state-of-the-science accuracies for oceanic surface temperature, currents, wave height, atmospheric temperature, mixed layer depth, surface winds, and related variables.

Achieving this objective will allow the calculation of comprehensive fields of oceanic and atmospheric boundary layer information, which will be useful for scientific research (such as the Earth System Science research program) as well as for a number of pratical purposes (such as general marine operations, search and rescue operations, oil spill dispersal estimates, ocean dumping assessments, ship routing, marine weather forecasting, and fishing operations). For example, this capability would foster the development of mesoscale-resolution, ocean-circulation models that can be used for applications. If the capability is not achieved, we will be less able to understand global as well as regional phenomena such as atmosphere-ocean heat and moisture transfers, carbon dioxide assimilation by the ocean, and El Niño. Furthermore, improvements in marine resource extraction and in marine resource management will continue to be inhibited, leading to lost economic opportunities and immediate economic losses. The major risk is the uncertainty of sufficient satellite remotely sensed data on a reliable basis in the time frame of interest.

The user community for the ocean applications objective comprises

Government and Government-Sponsored Users

- National Ocean Service
- National Weather Service
- Agencies
  - Department of Defense (DOD)
  - Coast Guard
  - Department of Energy (DOE)
  - U.S. Department of Agriculture (USDA)
  - Department of the Interior (DOI)
- Oceanographic and meteorological researchers
- Major research institutions
  - Institute for Naval Oceanography (INO)
  - Jet Propulsion Laboratory (JPL)
  - National Center for Atmospheric Research (NCAR)
  - Goddard Space Flight Center (GSFC)
  - Environmental Research Laboratories (ERL)

Commercial Users

- Value-added weather forecast firms
- Marine operations
- Offshore exploration and development
- Planners for energy, water, etc.
- Agricultural planners
- Recreational boaters

Measurement and Model Requirements: Ocean

Figure 5-11, the ocean timeline, provides an overall perspective on the structure and phasing of this effort.

Virtually all satellite remotely sensed and in situ data available in real time on the physical fields of the lower atmosphere and upper ocean will be used. These include operational and research data bases and involve measurements of temperature, winds, currents, sea height, waves, moisture, and salinity. The research data bases are used for model development and technique demonstration. Requirements for accuracy and resolution are the state-of-the-science capabilities projected for the early to mid-1990s. Our goal is hourly temporal resolution and 2-km spatial resolution. To achieve this goal, high-quality oceanic and atmospheric boundary layer models (probably coupled) will be required. Also, good quality regional atmospheric and oceanic circulation models will be needed to specify advective fields for the boundary layer models.

A number of research algorithms for retrieving geophysical data from satellite data need to be improved, and new algorithms for extracting surface layer salinity, mixed layer depth, marine boundary layer moisture and temperature, and flow-field estimates would enhance this effort. Data from the Special Sensor Microwave Imager (SSMI), Synthetic Aperture Radar (SAR), ocean color instruments, and so forth may be useful for some of these field estimates. Validation data will be needed with mesoscale resolution. These will best be obtained in concert with ongoing and planned oceanic mesoscale and air-sea interaction experiments. Access to Class VII computers will be essential; access to planned data networks is expected to be adequate without particular efforts by NASA.

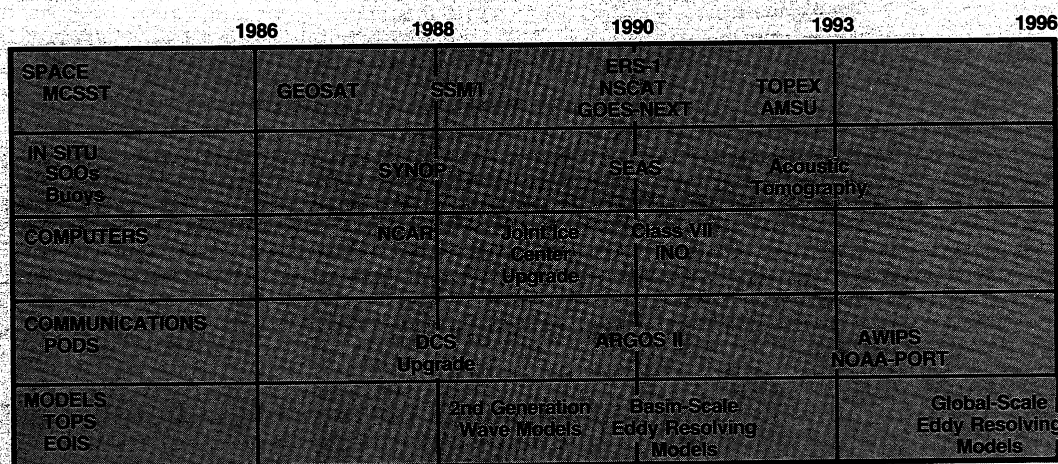
Current operational capabilities are not adequate to realize this objective, and substantial model development, including four-dimensional data assimilation schemes, will be required. For example, methods are required to assimilate altimeter-height data (for the oceanic circulation model), significant wave height and wave spectral data (for the wave model), and scatterometer-wind data and currents (for the atmospheric and oceanic circulation models).

For data assimilation schemes, error models using simulated and observed data will be needed for all components of the observing system, as well as good knowledge of the correlation structure of the physical fields. The general topic of model adjustment to incomplete data sets will be of particular importance for coupled air/sea models.

Special efforts should be made to exploit opportunities for model/data assimilation method developments presented by high-density observing periods associated with major experiments: Synoptic Ocean Prediction (SYNOP), Ocean Prediction Through

Given the joint responsibilities and interconnections between the Navy and NOAA, there are a number of unique factors that must be carefully considered when the oceanic subsystem reaches operational status.

Figure 5-11
Ocean Resource Timeline



AMSU	*Advanced Microwave Sounding Unit*
AWIPS	*Advanced Weather Interactive Processing System*
DCS	*Data Collection System*
EOIS	*Earth Observing Information System*
ERS-1	*First Earth Remote-Sensing Satellite (ESA)*
GEOSAT	*Navy Geodetic Satellite*
GOES-NEXT	*Geostationary Operational Environmental Satellite*
MCSST	*Multichannel Sea Surface Temperature*
NCAR	*National Center for Atmospheric Research*
NSCAT	*NASA Scatterometer*
PODS	*Pilot Ocean Data System*
SEAS	*Shipboard Environmental Acquisition Systems*
SSM/I	*Special Sensor Microwave Imaging*
SYNOP	*Synoptic Ocean Prediction*
TOPEX	*Ocean Topography Experiment*

Observation, Modeling, and Analysis (OPTOMA), Tropical Ocean Global Atmosphere (TOGA) program, World Ocean Circulation Experiment (WOCE), University Research Initiative Program (URIP), and so forth.

A set of bona fide prediction experiments will be needed in the applications areas of atmospheric visibility, fog, and icing, and in oceanic frontal developments. They might typically run for a month or so and involve hindcasts, nowcasts, and forecasts. Studies are required of the systems' sensitivity to input variables and the range of accuracy and resolvable scales.

Major Technical Milestones

1987-1989

- Assemble and evaluate atmospheric and oceanic boundary layer models
- Assemble and evaluate relevant geophysical data retrieval algorithms
- Design and develop four-dimensional data assimilation schemes

1989-1991

- Test and evaluate four-dimensional data assimilation schemes against NOAA, Seasat, and other data sets; model-simulated fields; and field experiments
- Design and plan prediction experiments

1991-1993

- Conduct prediction experiments in a variety of regions (off the East Coast, West Coast, Gulf Coast, Marginal Ice Zone) in different seasons
- Utilize NSCAT, TOPEX, ERS-1 data sets

1993-1995

- Conduct demonstrations (see Demonstration Projects)

Operational System Requirements: Ocean

The operational system into which the oceanic subsystem will fit is already partly in operation, dispersed between two agencies. The Navy maintains the Fleet Numerical Oceanography Center (FNOC) in Monterey, California. FNOC produces a limited suite of oceanic fields and forecasts for naval operations. NOAA operates an Ocean Products Center (OPC) colocated with the National Meteorological Center (NMC) in Camp Springs, Maryland, where special products are created and distributed for civil oceanic operations. The Navy and NOAA jointly operate (under Navy leadership) the Joint Polar Oceanography (Ice) Center (JIC) in Suitland, Maryland, where ice fields are mapped from diverse data and distributed to both the Navy fleet and civil interests. Finally, the Navy and NOAA will share data fields, products, and raw data through the Shared Processing System (in which the Air Force is the third partner). It is anticipated that in 1987 all of the oceanic data fields prepared by FNOC will be available to NOAA and others through that link.

User requirements. Given the joint responsibilities and interconnections between the Navy and NOAA, there are a number of unique factors that must be carefully considered when the oceanic subsystem reaches operational status. There is always a question of some of the data from the Navy being classified, which has previously been handled by the agencies in a case-by-case manner. Also, in any joint operation, in situations where the system is stressed and not all services can be provided, the needs of national security may necessarily take precedence. Arrangements in the oceanic subsystem must be made for both of these factors.

Data delivery. The weather-related products (winds and waves) from the operational oceanic subsystem must be available in near-real-time to be useful. For example, the products relating to ocean currents and ice must be available within 24 hours or less. These timing requirements are well laid out in planning reports of the Navy (e.g., NSCAT) and NOAA (e.g., for the ocean service centers and from the National Environmental Satellite, Data, and Information Service [NESDIS]) in Envirosat 2000 reports).

Communications. Some of the needed operational communications systems are expected to be established during the development of the subsystem. These include the Shared Processing links and NOAA-PORT. The subsystem should be designed to take advantage of these links. Other data links, like that for TOPEX winds and waves, will have to be designed into the subsystem before it can become operational.

Computational resources. In principle, both agencies (Navy and NOAA) have accepted the results of the oceanic objectives and have called for development of the subsystem. NOAA and Navy have agreed to update the Joint Ice Center to allow it to manipulate digital imagery; this will make it compatible with the oceanic subsystem. Navy has expressed interest in access to European Space Agency (ESA) Earth Remote-Sensing Satellite (ERS-1) data, and both NOAA and NASA are seeking agreements with ESA to provide the United States with access to the data. In short, the agencies are taking actions that suit the development of an operational oceanic data subsystem.

There is general agreement between NOAA and Navy regarding the geographic scope of the activities of each in areas that might affect the oceanic subsystem. Navy will take responsibility for global fields and operational products. NOAA will take responsibility for operational products aimed at the Exclusive Economic Zone of the United States. Neither of these is intended to be exclusive nor to preclude the other agency from doing work directed at the larger or smaller geographic area. The subsystem may have to be designed to feed part of the products to one agency and part to the other (e.g., U.S. Exclusive Economic Zone regional products to NOAA and global and other regional products to Navy).

Ancillary data sources. No major additional computer power beyond that already planned should be needed to handle the oceanic subsystem in the operational centers. The upgrades to Class VII computers at NMC and FNOC, plus the planned upgrade at JIC, should be sufficient. In any case, the oceanic subsystem design should assume the planned computer capabilities.

Training. Significant training of personnel at all three operational centers (FNOC, OPC, and JIC) is anticipated for these new product streams. The training needs may differ among the three and these differences should be taken into account in designing the subsystem.

Costs. The costs of the operational system that derive from the oceanic subsystem will be distributed among the agencies but will have to remain a small additive cost to ongoing systems. We estimate that a maximum acceptable level would be on the order of several million dollars per year. As with the atmospheric subsystem, we expect that NOAA will charge user fees to recover the marginal costs of providing the service to private users.

Besides NOAA and Navy, several other agencies will be intensely interested in the oceanic subsystem, including the Coast Guard, the U.S. Geological Survey, the Minerals Management Service, the Army Corps of Engineers, and the Maritime Administration. These agencies, as ultimate users, should be consulted in the design of the subsystem.

During recent discussions of NOAA's proposed ocean service centers, the division of roles between NOAA and the private sector with regard to tailored products was considered. NOAA's policy is to provide global and regional products over certain geographic limits, and the private sector will provide any special products for specific market sectors. This distinction should be maintained in the design of the oceanic subsystem. The system should provide for external users as the National Meteorological Center does with its family of services.

Besides NOAA and Navy, several other agencies will be intensely interested in the oceanic subsystem, including the Coast Guard, the U.S. Geological Survey [etc.] . . . . These agencies, as ultimate users, should be consulted in the design of the subsystem.

Demonstration Projects: Ocean

The method of demonstrating that the information system meets the applications objective will be to test the nowcast assimilation algorithm against the existing operational system at FNOC. The new system will be able to use all unclassified operational data sources and new research systems (e.g., NASA's TOPEX, ESA's ERS-1) to meet its objectives. The outputs from the demonstration system will be the gridded variables defined above. The value of each data source will be demonstrated by methods such as selective omission. Accuracy will be tested by in situ experiments such as SYNOP, OPTOMA, and WOCE, and forecasts will be tested against the outputs of the data assimilation scheme.

Performance measures will include the following, and a detailed test plan must be defined as part of the research program.

- *Accuracy Measures*—These are defined in the objectives statements and must be demonstrated in a statistically significant number of cases, accounting for different seasons and geographic areas.
- *Timeliness*—The system must create hourly values of the variables within 1 day. The system must function as a responsive on-line system to a variety of users.
- *System Interface*—The system must be simple and responsive to encourage use by groups of varying levels of expertise.
- *Potential for Operational Implementation*—The demonstration system must show the capability for operational implementation (i.e., robust against single point failures; capable of stable, routine performance without extensive, expert manual intervention; and having well-defined routine outputs).

The schedule for the demonstration can be summarized as shown below. This will allow time for final revisions during 1996.

- *Component Demonstration*—Demonstrate various system modules by 1991 to peer review group.
- *Regional/Regime Experiments*—Show capabilities to meet system performance measures in diverse geographical areas in all seasons. Include periods of week-long forecasts by 1993.
- *Year-Long Prediction System Demonstration in the U.S. Exclusive Economic Zone in 1995.*

Technology/Methodology Transfer Process: Ocean

The technology transfer process involves two phases. First, the transfer of hindcast/nowcast/forecast information products will consist of the successful transition of the production, distribution, and archiving from a research to an operational status. Second, the transfer of new algorithms developed during the research phase for data assimilation and forecasting will mean the distribution and acceptance of these algorithms into the wider research community as a basis for further development. The operational center at FNOC will implement this process.

Transfer will take place from NASA and Navy, as the principal development agencies, and from their research collaborators, such as NOAA and NSF. Transfer will occur to three distinct types of organizations:

- End users whose interest will be entirely in the concrete hindcast/ nowcast/forecast information products

The information systems developed . . . will provide immediate benefits for decisionmakers involved in economic planning, agriculture, energy, and water resource management.

- Operational services, such as NOAA and the Department of Defense (DOD), which will become the operational users of the new algorithms
- Researchers who will be users of both the information products and the new algorithms

For a successful transference, very close teaming between the research and operational organizations is necessary from the start of the development program. The programs must be conducted within the context of the constraints on operations, budget, and personnel of the eventual target agency. Simultaneous relevant events presented in Figure 5-11 are also critical influences and must be carefully integrated.

There is a set of established and exercised guidelines and practices for NASA and NOAA cooperation, which must be maintained, and they may need to be elaborated to specifically support coordination of these applications developments.

To allow successful development and operation, it is necessary to assign overall responsibility as follows:

- NASA and Navy should be responsible for leading the research program. NOAA and other researchers should function as "subcontractors" to NASA; NASA and Navy responsibility will extend through the period of transfer into operational service.
- NOAA and Navy should be responsible for operational service. The assumption of this responsibility must begin with planning for the continuous and smooth transfer to operational service.
- NASA and Navy will maintain a continuing responsibility for leading further research in order to consider future improvements. NASA-sponsored researchers will be major users of the operational system's products.

The transfer period is critical, in part because of the necessity for shared responsibility. Planning for a smooth transition should be conducted carefully, with special attention given to discontinuous changes during the operational transfer (e.g., the application of user fees to researchers). Plans should be developed to avoid such problems.

An attempt to outline a total funding start-up, development, transfer, and initial operation indicates that the undertaking is significant. A rough estimate of approximately $2 million in 1987, followed by a $4-million budget for 1988 and $6 million for 1989, would be appropriate for start-up. The $8-million level would be roughly constant through 1991, and then grow to about $12 million for 1992-1995 to support validation and demonstrations. This total budget would be divided between NASA, NOAA, Navy, and other researchers. Transition into operational service would probably demand a government expenditure of about $8 million per year on a continuing basis.

Atmosphere Objective

Develop and validate by 1993 an atmospheric information system for weekly, monthly, and seasonal values of climate parameters including temperature, humidity, rotational and divergent components of the wind, soil moisture, ice and snow cover, precipitation, and surface and atmospheric albedo.

The system should provide these values globally at one-degree latitude/longitude intervals through a process of four-dimensional data assimilation. Temperature and wind are to be specified at 15 or more levels from the surface to 10 mbs and humidity at 3 or more levels from the surface to 300 mbs. Desirable accuracies are 0.8° C for temperature, 3 m/sec for wind, 10 percent for humidity and albedo, and 30 percent for soil moisture.

Achieving this objective will foster research on global atmospheric processes, allow monitoring on a global basis of short- and long-term climate change, and provide the capability to develop and validate new extended-range weather and climate forecast techniques. If the capability is not achieved, we will be less able to detect, in a timely fashion, important anthropogenic and natural variations in climate, to understand adequately the sensitivity of climate to external forcing, or to validate models designed to simulate or predict global climate and climate change. The information systems developed under this objective will provide immediate benefits for decisionmakers involved in economic planning, agriculture, energy, and water resource management. Longer term benefits will result from research made possible by the new information systems.

This particular objective was selected because of the importance of developing an improved capability for global climate monitoring and prediction, the central role of remotely sensed data from space in this effort, and the high level of NASA expertise in development of geophysical algorithms and in modeling of the global atmospheric circulation.

Observations, computers, communications systems . . . and global numerical assimilation and forecast models are the tools required to achieve measurement and model objectives.

Measurement and Model Requirements: Atmosphere

Observations, computers, communications systems for acquisition of observations and dissemination of information, and global numerical assimilation and forecast models are the tools required to achieve measurement and model objectives. The current and projected capabilities through 1993 in each of these areas are summarized in Figure 5-12.

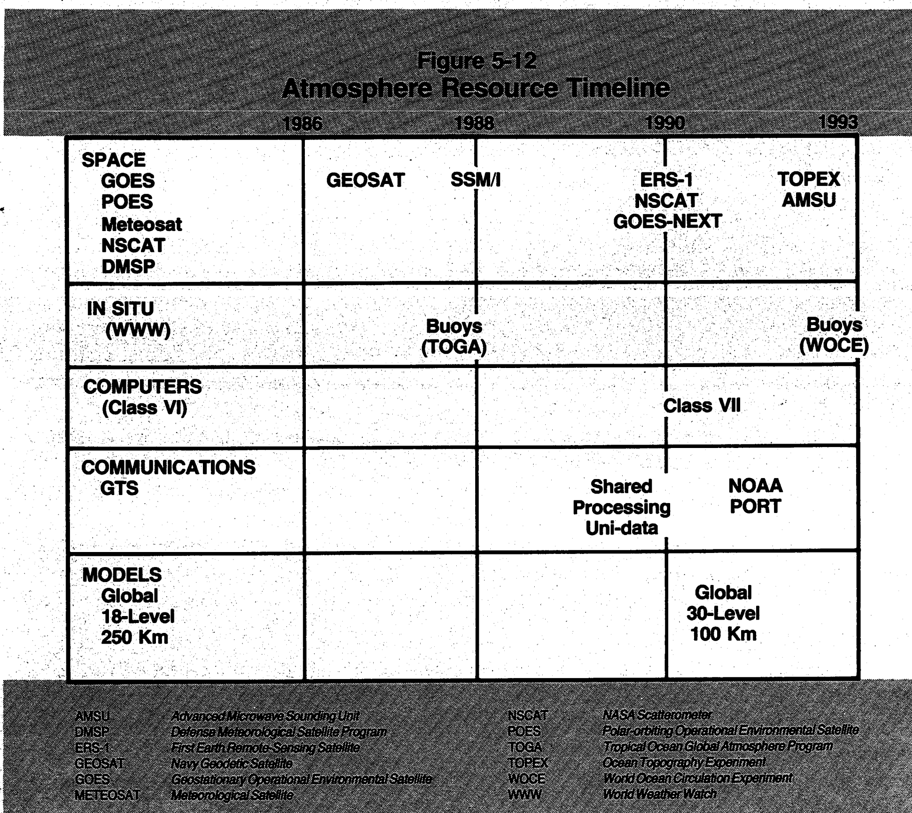


Figure 5-12
Atmosphere Resource Timeline

Observations include those available routinely at U.S. operational centers (NMC, AFGWC, and FNOC), as well as buoy and satellite observations collected under national or international research programs. Data requirements are global. No special new sensor systems are either required or likely to be available to meet the 1993 objective; however, continued availability of geostationary and polar-orbiting satellites is assumed. Improved sensing capabilities on planned operational and experimental satellites are critical to the achievement of the accuracies stated in the objective.

Primary limiting factors for success are the accuracy with which algorithms can be developed for extraction of geophysical data from satellite sensors, the fidelity of numerical models used for data assimilation, and the inability in this time frame to obtain wind profiles in the tropics from remotely sensed data.

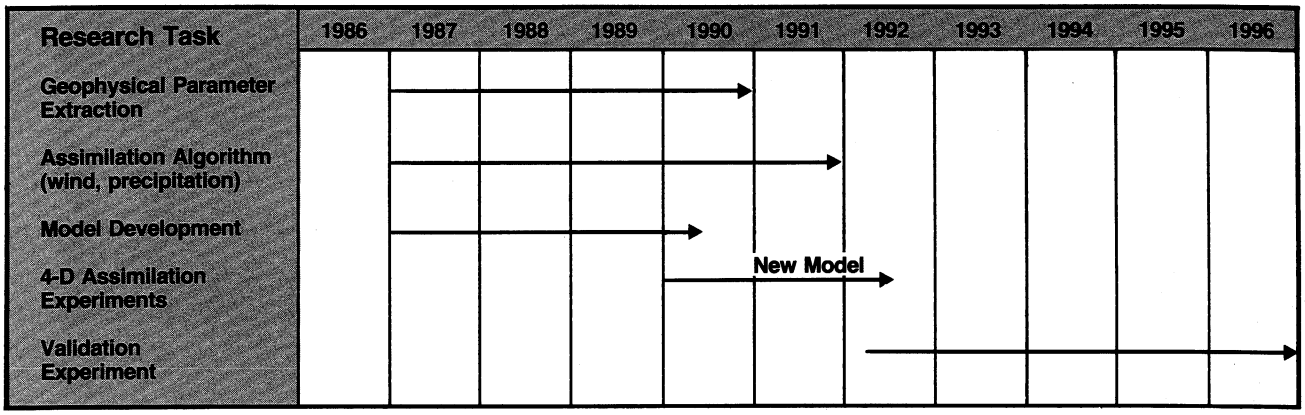
Current numerical algorithms and models are not adequate to achieve the accuracies stated in the objective. Major research efforts are required to improve the extraction of geophysical variables (particularly soil moisture, albedo, precipitation, and water vapor) from current and planned sensor data, to develop or improve methods for assimilation of derived geophysical data, and to improve the fidelity of global forecast models. Both simulated and real data experiments should be conducted to validate the accuracy of model-generated variables.

An approximate time schedule for the research efforts required to achieve this objective is shown in Figure 5-13.

Operational System Requirements: Atmosphere

NOAA's NMC and its component Climate Analysis Center will be the primary operational centers in which the atmospheric information system will reside.

Figure 5-13
Research Task Timeline



NMC is the core of the National Weather Service analysis and forecast program, providing forecast guidance to field offices, other Federal agencies, private meteorologists, and—under a variety of international agreements—to weather services of other nations. The Climate Analysis Center analyzes and disseminates real-time climate information and issues monthly and seasonal forecasts of average weather conditions. Both of these organizations have research and development components and researchers from the operational centers would work collaboratively with NASA scientists in development of the new information system.

Since 1978, NMC has run a global data assimilation system as part of its routine, daily operations. This system, developed collaboratively with NASA to support the Data Systems Test and Global Weather Experiment, is now a fundamental component of the Center's numerical forecast and climate monitoring function.

Improved methods for data assimilation developed under this objective will replace or update the present global capability of NMC. Thus, the atmospheric information system must be designed to fit within feasible operational constraints.

User requirements. Because an operational meteorological assimilation system is currently in place and serves a multitude of users, requirements are strict for continuity, stability, timeliness, documentation, and well-characterized products for the operational component of the new information system. The new system must meet the standards of the ongoing system from the very first day of operation. To become operational, new techniques will need to undergo quality control and verification and will need to be documented according to operational standards.

Systems for dissemination of information are likewise in place. Thus, planning for information access and dissemination will need to take into account existing systems and the needs of users of these systems. NASA and NOAA plans for providing this information to users will need to be fully coordinated. In general, each agency is likely to identify its users and respond to their particular requirements. Information and, whenever feasible, systems generated under this objective should be shared between the two agencies.

Planning for information access and dissemination will need to take into account existing systems and the needs of users of these systems.

The information system must be improved as new sensors become available or better techniques are developed for data extraction, data assimilation, or modeling of the global atmosphere. This will require a continuing research component of the system, probably maintained by NASA, with full access to both operational and research data. Capabilities must be maintained to rigorously test the validity of new procedures against those in use in the operational system and to document the effects of the changes to users.

Data delivery. The weekly averaged data generated by the operational component of the information system should be available 1 day after the data have been assimilated at the end of the normal work week. Monthly averages should be available within 2 days after the end of each month. Because of the constraints that will exist within an operational environment and the utility of intermediate assimilations for operational forecasting, the assimilation process must be carried out routinely each day, with a time delay of no more than 6 hours between taking an observation and its use in the assimilation system.

The research component may operate in a much more delayed mode. However, it must be designed to assimilate a day's data in less than a day to provide timely results to NASA principal investigators.

Computational resources. Peak processing rates required for retrieval and assimilation of data with the resolution and accuracy required are of the order of 10 gigaflops. Central memory requirements are at least 32 million words. Computer resources of this magnitude will be available, during the time period considered, at only a few major operational and research centers. We anticipate that by about 1990 NOAA's NMC and perhaps several NASA laboratories will have this capability.

Cost. In operational use, any additional capabilities need to be conservative and inexpensive. They should not dramatically alter the operational system, and the incremental cost to use the new capability should be only a few percent of the ongoing operations costs.

The atmospheric information system must take into account the existence of an active commercial market for weather services. The design should avoid any negative competitive impact on this commercial marketplace. The design can and should ensure stability in performance as a basis for future markets.

NOAA has a requirement to charge user fees where there are marginal additional costs of serving users. Because the products of the operational information system will fall within the usual role of NMC, the fees will likely be hookup fees and nominal charges for any additional computer time for handling the service of outside users.

One unique feature of the atmospheric information system is its potential impact on a long-standing collaboration among all nations through the World Meteorological Organization. All weather data acquired worldwide are freely shared (at no cost) with all nations through this organization. This system must not alter that arrangement nor have an adverse impact on it.

The new system to be developed will be able to use both existing, unclassified operational data sources as well as new research data sources . . . to meet its objectives.

Demonstration Projects: Atmosphere

The method of demonstration for the atmospheric data system will be first to test the system against the existing operational system at NOAA/NMC. The new system to be developed will be able to use both existing, unclassified operational data sources as well as new research data sources (e.g., NASA's TOPEX, ESA's ERS-1) to meet its objectives. The demonstration outputs will be the grids of parameters (defined in the objectives section) produced by the assimilation algorithm. Accuracy will be tested by special validation data sets. These validation data sets may be historical (e.g., from the Global Atmospheric Research Program) or acquired during validation exercises by new instrumentation to be available at that time (e.g., wind profilers).

A variety of performance measures will need to be considered to evaluate overall system performance. Part of the research plan will be to define an acceptable test plan. These measures include the following:

- *Accuracy Measures*—These are defined in the statement of objectives, and they must be demonstrated in a statistically significant number of cases in several different weather regimes.
- *Timeliness*—The climatology system must create weekly values within 1 day after the end of the week. The system must function as a responsive on-line system to a variety of users.
- *System Interface*—The simplicity and responsiveness of the system will be an important factor in determining the number of potential users, which will be a significant evaluation parameter.
- *Potential Operational Implementation*—The demonstration system must show the capability for operational implementation (i.e., robust against single point failures; capable of stable, routine performance without extensive, expert manual intervention; and having well-defined routine outputs).

A year-long demonstration will be conducted from mid-1991 to mid-1992. This will provide sufficient time to demonstrate the system performance in various regimes of weather to a variety of users.

Technology/Methodology Transfer Process: Atmosphere

Two types of developments are being transferred. Retrospective/present/forecast information products will undergo the transition of their production, distribution, and archiving from a research to an operational status. The new algorithms developed during the research phase for data assimilation and forecasting will begin to be distributed to and accepted by the wider research community, providing a basis for further development. Algorithms will also be transferred to NMC for operational implementation.

To achieve successful transfer . . . very close teaming between NASA and the NOAA operational agencies is necessary from the start of the development program.

Transfer will take place from NASA, as the principal development agency, and from its research collaborators. Transfer will occur to three distinct types of organizations:

- End users, whose interest will be entirely in the concrete retrospective/present/forecast information products
- Operational services, principally NOAA/NMC
- Researchers, who will be users of both the information products and the new algorithms

To achieve successful transfer, it is clearly recognized that very close teaming between NASA and the NOAA operational agencies is necessary from the start of the development program. In addition, the development must be conducted within the context of the constraints on operations, budget, and personnel of the eventual target agency. Simultaneous relevant events shown on the timeline (Figure 5-13) are also critical influences and must be carefully integrated.

To ensure that the research phase is focused on operational problems, research must be done in close collaboration with the operational centers. It is equally important that the operational setting be receptive and ready to implement the new techniques. There are several ways to achieve this, but the best include some interchange of personnel and the colocation of some of the activities with the operational center.

We therefore propose a model for the activities along the following lines:

- All participants must agree (at a minimum) on the "numerics" inherent in the operational model to be used throughout the research activities.
- Part of the research must be undertaken by academic or NASA personnel at the site of the operational center (to this end, NOAA would make available office space, some personnel, and access to the operational computers as its contribution to the activity).
- At the operational center, research would be done on the actual hardware and operational models to develop and test assimilation techniques and forecast capabilities. (This would allow tests of timeliness and the fit of the techniques into the operations; it would also likely lead to early transition to operations of some simpler techniques as they are developed.)
- Part of the research should be undertaken at major research centers (e.g., Goddard Space Flight Center), where the operational agencies would place a small cadre of operational personnel to take part in the research.
- Research at these centers would be of a more speculative and risky type, and there would be no constraints on the timeliness of the activities (the long-term and more dramatic changes in the operational systems could be investigated better here).
- Personnel should be rotated between the operational and research settings on some reasonable time frame.

NASA and NOAA have an extensive history of cooperation, and there is a set of established guidelines and practices for such cooperation. It is important to maintain awareness of these policies and to elaborate them as required, specifically to support coordination of the development for these applications.

To allow both successful development and operation, it is necessary to assign overall responsibility to the two agencies. The assignments understood include the following:

- NASA and NOAA should share and apportion responsibility for the research required to develop the new information system. NASA's shared responsibility will extend from the research phase through the period of transfer into operational service.
- NOAA should be responsible for operational service. The assumption of this responsibility must begin with planning for the transfer to operational service; transition of responsibility from NASA to NOAA must be continuous and smooth.
- NASA will maintain a continuing responsibility for further research in order to consider future improvements. NASA researchers will be major users of the operational system's products.

The period of transfer is a critical one, in part because of the necessity for shared responsibility. It is important that planning for a smooth transition should be carefully conducted. As a component of this planning, special attention should be given to avoiding changes that would cause discontinuity at the time of operational transfer, particularly such items as the application of user fees to researchers. Plans should be developed to avoid such problems.

An attempt to outline a total cost of this program, from development and transfer through initial operation, indicates the significance of this undertaking. A rough estimate of approximately $2 million in 1987, followed by a $4 million budget for 1988 and $6 million for 1989, would be appropriate for start-up. The $8 million level would be roughly constant from 1990 through 1996.

NASA and the operating agencies both would commit resources with appropriate shares yet to be negotiated. It is assumed that, to a large degree, funding would be provided from reprogramming of available monies; however, additional funding may be required to attract a sufficiently large and talented group of academic researchers to the program and to accomplish technology transfer from research into operations.

The major need is to link the existing operational facilities with research centers within NASA and with the external research communities for the purpose of improving forecasts.

Information System Requirements: Ocean and Atmosphere

The ocean and atmosphere applications differ from the nonrenewable and renewable resources applications in that a large government-owned and operated, integrated system of data handling exists within the ocean and atmosphere operational agencies. The major need is to link the existing operational facilities with research centers within NASA and with the external research communities for the purpose of improving forecasts. This linkage should include limited on-line communications facilities, the mailing of data products, and the exchange of personnel. At a later stage, a larger community will need to gain access to the gridded data fields.

Users

The users involved in the ocean and atmosphere applications will vary during the five phases envisioned for the program.

Initial phase. The National Meteorological Center, the Fleet Numerical Oceanography Center, the Naval Oceanographic Office, and the Goddard Space Flight Center will serve as lead institutions and will establish their terms of reference and plan their joint activities.

Development phase. During the development phase, additional institutions will be added to those active in the initial phase. The aggregate of about 12 will participate in the development and testing of new algorithms. The National Center for Atmospheric Research, the Institute for Naval Oceanography, the Geophysical Fluid Dynamics Laboratory, and several universities will join the program for this phase.

Demonstration phase. During the demonstration phase, additional university researchers and the international community will be added to the program, and all of them will assist in testing the new routines. A total of about 30 institutions is envisioned.

Transfer phase. During the transfer phase, the accepted algorithms will be transferred from the research groups to the National Meteorological Center, the Fleet Numerical Oceanography Center, and the Naval Oceanographic Office.

Operational phase. The operational centers will use the new techniques and algorithms to provide data to their operational users and to future researchers.

Data

With the exception of the test data sets required for the development phase, the required data will be available from the existing and planned operational data systems.

Remotely sensed data. Data will be used from all existing and planned weather- and ocean-related satellites (see Figures 5-11 and 5-12, respectively, for timelines of the ocean and atmosphere data resources).

Validation data. These will include sample data from all operational sources for specified periods. About 100 high-density tapes, resident at Goddard Space Flight Center and moved on request by mail to development phase users, will contain the basic data needed for this activity.

Auxiliary data. All currently used in situ data from the operational systems will be used (see Figures 5-11 and 5-12).

NASA should support a project bulletin board for users and a standard algorithms library and should provide the necessary communications networks for all user service functions.

Standards for Quality Assessment and Documentation

Data standards and format guidelines for data products are being established internationally by the Committee on Environmental and Operational Satellites and the Consultative Committee on Space Data Systems. Using currently accepted operational formats as a starting point, and with the cognizance of the Committee on Environmental and Operational Satellites, we recommend setting up a standards working group composed of participants in the application program. Standards for in situ data must also be considered.

A directory of the NOAA environmental satellite and other archives (including libraries of standard test data) should be available on-line, showing holdings and their locations. A query-based catalog to provide additional information and a browse file containing sample data should also be available. These capabilities would permit users to order the data required. The outcome should be a delivery order for the data via magnetic tape by use of an on-line ordering capability. This total capability could be developed as an extension of the present NOAA/NEDRES system and other directory and catalog systems being operated and developed by NASA.

NASA should support a project bulletin board for users and a standard algorithms library and should provide the necessary communications networks for all user service functions.

Software regularly supported by existing operational facilities will be needed. This includes operational algorithms for data quality control, data analysis initialization, and forecast models. The Global Data Assimilation System and Geophysical Data Record operational algorithms will be needed. Research-generated developmental algorithms (nonoperational software) will be used.

Existing and programmed computational facilities at NMC, FNOC, and GSFC, augmented by a high data rate communications link between NMC and GSFC, are required to support the shared computing environment. The use of existing and programmed computing facilities at participating outlying laboratories (e.g., GFDL, NCAR, INO, and universities) and international collaborators is anticipated. Some augmentation will be required for input/output at NMC and GSFC. A relatively modest computer and programming support effort will be needed at GSFC to maintain the directory, catalog, inquiry system, bulletin board, algorithm library, and browse capability. No major new purchases are identified.

Improved access to in situ data is needed. This requires continued support of such programs as NOAA's Shipboard Environmental Data Acquisition Program, Data Collection Platforms Program, radiosondes, and so forth. It also requires some augmentation of existing archival data bases and continuation of the upgrades to the Global Telecommunications System. There may be a need for work stations with color graphics at some research sites. No new large developmental tasks or major new purchases are identified. It is assumed that it will be possible to work cooperatively with ongoing programs on the ground and in space (e.g., Genesis of Atlantic Lows Experiment [GALE], WOCE, ERS-1, MOS-1) and that interfaces with data bases from other disciplines will be established to augment the data collected specifically for this program.

Recommendations

To be positioned to utilize prospective oceanic and atmospheric satellite data streams effectively for applications as well as scientific research, a research program on four-dimensional data assimilation schemes (i.e., the integration of all available germane observations with the aid of appropriate models to make full four-dimensional field estimates) is recommended for both oceanography and meteorology. The applications focus is the oceanic mesoscale and the atmospheric long-range weather/short-term climate scale. To implement this recommendation, an information system will be required that enhances the existing operational information systems to include university and other researchers in a fashion that meets their particular needs.

To ensure timely results, and a successful transition to operations, a series of oceanic and atmospheric prediction experiments and demonstrations is recommended.

Information System Architecture

6

The information system is being viewed as the key to major advances in the application of remote sensing. The recent report of the Earth System Sciences Committee entitled "Earth System Science: A Program for Global Change" asserts:

> *Of paramount importance to the success of Earth System Science is an advanced information system that will promote productive use of global data. The worldwide space and in situ observations required for a deeper understanding of the Earth System can be utilized only if the research community has effective access to them. The design, development, and management of the requisite information system are tasks that approach, in scope and complexity, the design, development, and operation of space-based observing systems themselves.*

What is envisaged is the gradual and symbiotic development of a system where the users might access disparate data sets at many geographic locations within the research and applications communities to perform a complete spectrum of studies ranging from specific individual efforts to broad interdisciplinary problems. The selection, here, of specific applications to drive development of the information system recognizes the need to proceed as quickly as possible with some relatively modest first efforts while acknowledging the need to anticipate and foster more extensive future technical capabilities.

In the more specific terms of this remote-sensing applications approach, data from numerous instruments and other sources will be required by multiple users in Federal agencies, academic institutions, and private industry. Rather than satisfying data and information requirements and capabilities piecemeal, the attempt is made to develop an overall umbrella concept early in the program, which can serve as the basis for a cohesive, integrated approach to the system architecture. This approach should be more productive, be burdened with less ultimate overhead cost in terms of personnel and logistics, be more transferable to the ultimate users, and better facilitate the broad disciplinary and interdisciplinary studies than a more uncontrolled one.

A large degree of commonality does exist for some elements of the [resources and ocean/atmosphere] subsystems. Thus, it is believed that a single unifying Applications Information System concept is possible and advantageous.

Applications Information System Architecture

There is considerable commonality in the information system requirements of the renewable and nonrenewable resources applications programs. This is because they use many of the same data sources, and the methodologies employed by the investigators are similar: they both require that remotely sensed imagery be geocoded and use similar geographic information systems. Thus, it is possible to describe a single system concept for the renewable and nonrenewable land resources applications programs and expect that it can be implemented.

It is also true that the ocean and atmosphere applications have a similar level of commonality. Thus, a single system concept and implementation appear possible for the ocean and atmosphere applications programs.

It is unlikely that all elements of the systems serving the land resources and the ocean and atmosphere disciplines can be used in common. It is also unlikely that the large-scale facilities the operational agencies use in the ocean and atmosphere

The subsystem architecture should consist of modules that can be added to one another to form an integrated system . . . . This subsystem is compatible with the Eos architecture and will probably be one of the forerunners of that system.

programs would be available for the land resources applications programs. The differences between the current heavy emphasis on imagery by the land resources applications community and on gridded digital data by the atmosphere and ocean applications community lead to fundamentally different demands on the computational and data distribution resources. These factors have led to separate subsystem concepts for these two components of the applications program. It is emphasized, however, that cross-discipline exchange of data is a desirable goal, even in these initial applications. Planning should include provisions to facilitate this process with the expectation that these will lead to increased cross-discipline data use in the future.

However, a large degree of commonality does exist for some elements of the two subsystems (e.g., for the user support functions, which include the directories, catalogs, browse files, inquiry networks, ordering subsystems, their connecting networks, and their documentation). Thus, it is believed that a single unifying Applications Information System concept is possible and advantageous. This concept would employ common components where possible, but separate components where indicated by agency or technological constraints.

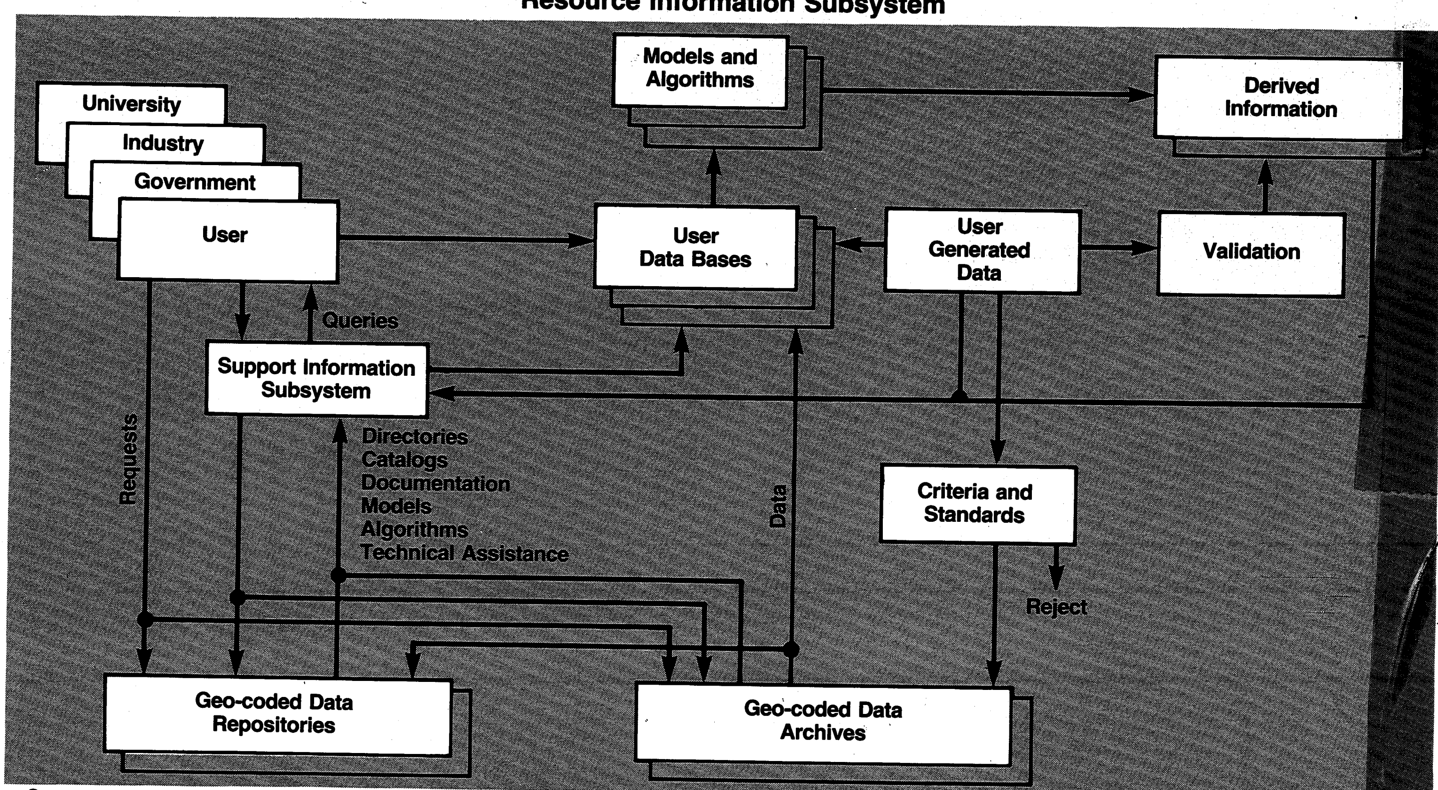
Resources Subsystem

Because of the wide diversity among the resources application demonstration objectives and their associated test sites, a distributed data and processing subsystem with a central user support capability is suggested.

As discussed in the previous section, the various investigators will be drawn from government, industry, and university communities. Each investigator will contribute to the building and use of a data base related to his or her test site. This data base will contain remotely sensed and in situ data, which will be merged, processed, and manipulated to derive the information desired for the investigation. In addition to the measurements, the user data bases may contain existing knowledge and other information related to the test site, such as climatic conditions, topography, geology, vegetation cover, land use, and depth to the water table. The investigators will be expected to generate special data sets needed by their models when they do not exist.

The user data bases are a central feature of the Resource Information Subsystem functional diagram presented in Figure 6-1. Primary inputs to these data bases will

Figure 6-1
Resource Information Subsystem



Commercial Satellites — EOSAT, SPOT. . . .
Government Satellites — U.S. (NASA, NOAA), Japan, ESA. . . .
Mapping Agencies and Outlets
Land Applications Archive
Other

be from the geocoded data repositories and archives, which provide data in standard forms for all users of the subsystem. It is anticipated that the repositories will encompass the mission and instrument repositories for many spacecraft, including United States and foreign operational land remote-sensing satellites. The archives will consist of already existing ones, such as the Department of Interior's EROS data center, as well as archives that may have to be established as a result of this program. The inputs for the user data bases also include special data sets generated by the users, including especially those related to the test sites. There will need to be mutually agreeable access procedures relative to proprietary commercial and other controlled data.

As Figure 6-1 shows, the user data bases serve as the inputs for the user algorithms and models. By the use of those algorithms and models, the users derive information which, after validation, is the primary product of the endeavor. This derived information, in addition to being disseminated by the usual publications and other distribution methods, serves as an input for further investigations. After appropriate screening against established criteria and standards, the information and data sets that are of general utility are placed into the archives for later use by others both within and outside the project.

A central part of the Resource Information Subsystem is the User Support Information Subsystem. It assists the users in acquiring and understanding their data and provides technical assistance. The User Support Information Subsystem should contain a directory listing available data and services and their locations. It should provide access to catalogs detailing the characteristics of the available data and of documents that describe such factors as data content, data preprocessing, and instrument calibration. In some cases the subsystem may provide access to on-line browse files and should also provide technical assistance or referral to needed assistance. Users should be able to make inquiries to the User Support Information Subsystem and receive information from it via standard public or private electronic networks, including ARPANET, NSFNET, SPAN, and the PSCN.

Once the desired data are identified and located, a user will request them from the appropriate repositories, archives, and other sources. In addition to the remotely sensed data, the user can request other geographic information, such as digital data files and maps related to topography and vegetation cover. These latter data may reside in commercial or public entities.

At least for the applications considered in this report, the requested data are expected to be delivered to the users on magnetic tapes or optical disks by mail, because the investigations will have a relatively low data volume and the phenomena being mapped or monitored will be varying slowly (the proposed measurements being on an annual or seasonal basis). Later applications, however, may require more rapid data delivery.

The subsystem architecture should consist of modules that can be added to one another to form an integrated system. It should be distributed both geographically and functionally, but with electronic communications to support the queries of the central directory, catalogs, and browse files, and other services. Also, it should include text exchange between users and an electronic bulletin board. This subsystem is compatible with the Eos architecture and will probably be one of the forerunners of that system.

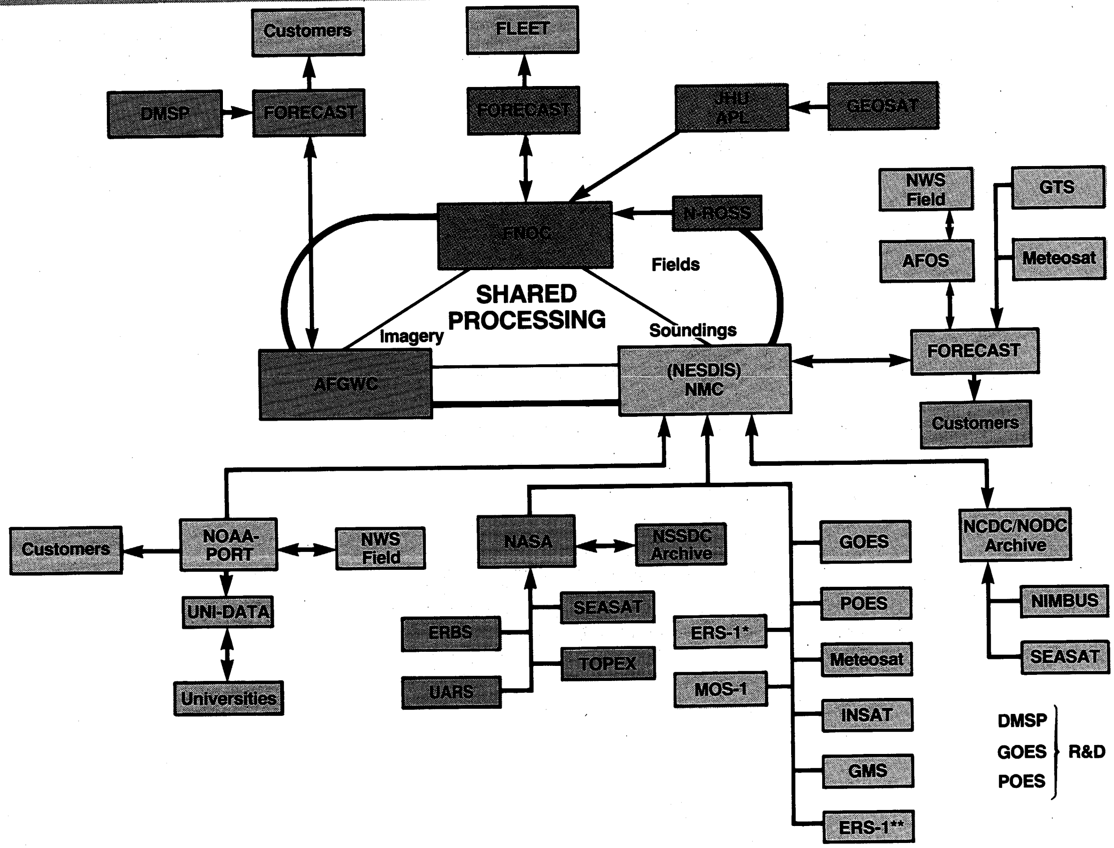
This [information] subsystem would allow multipoint, real-time access to the full range of operational, experimental, and test data, as well as to the supporting directory, catalogs, browse files, algorithm and test data libraries . . .

Ocean and Atmosphere Subsystem

A distinguishing feature of the information system for the ocean and atmosphere applications is that it will draw heavily on the established operational systems of NOAA, the Navy's Fleet Numerical Oceanography Center, and the Air Force Global Weather Central. The three-agency operational environmental services system anticipated for the period under discussion is shown in Figure 6-2. A summary of the expected capabilities and the timelines for implementing them are indicated in Figures 5-11 and 5-12 in Section 5. This complete system is based on an understanding between the three operational agencies that the primary contributions to the coordinated services will be quantitative atmospheric soundings, quantitative ocean parameter fields, and cloud and surface imagery, respectively; it is currently budgeted. To link this operational system to the nation's major governmental and university research programs, the connections to the NASA experimental programs and to the National Science Foundation Unidata system are indicated. The primary archives for the operational data are NOAA's National Oceanographic Data Center and National Climatic Data Center; NASA's National Space Science Data Center serves as the archive for a portion of the research data.

Augmentations of this basic capability to support the applications program are shown in Figure 6-3. Figure 6-3 represents the minimal configuration needed to

Figure 6-2
Ocean and Atmosphere Information Subsystem Currently Planned Network



KEY TO ACRONYMS

AFGWC	*Air Force Global Weather Central*	GSFC	*Goddard Space Flight Center*	NESDIS	*National Environmental Satellite, Data and Information Service*
AFOS	*Advanced Field Operations Systems*	GTS	*Global Telecommunications System*	NMC	*National Meteorological Center*
DMSP	*Defense Meteorological Satellite Program*	INO	*Institute for Naval Oceanography*	NODC	*National Oceanographic Data Center*
ERBS	*Earth Radiation Budget Satellite*	INSAT	*Indian National Satellite*	N-ROSS	*Navy Remote Ocean Sensing Satellite*
ERS-1	*First Earth Remote Sensing Satellite*	JHUAPL	*Johns Hopkins University Applied Physics Laboratory*	NSF	*National Science Foundation*
ERS-1	*Earth Resources Satellite*	METEOSAT	*Meteorological Satellite*	NSSDC	*National Space Science Data Center*
FNOC	*Fleet Numerical Oceanography Center*	MOS-1	*Marine Observation Satellite*	NWS	*National Weather Service*
GEOSAT	*Navy Geodetic Satellite*	NCAR	*National Center for Atmospheric Research*	POES	*Polar-Orbiting Operational Environmental Satellite*
GFDL	*Geophysical Fluid Dynamics Laboratory*	NCDC	*National Climate Data Center*	SEASAT	*Sea Satellite*
GOES	*Geostationary Operational Environmental Satellite*	NEDRES	*National Environmental Data Referral System*	TOPEX	*Ocean Topography Experiment*
GMS	*Geostationary Meteorological Satellite*			UARS	*Upper Atmosphere Research Satellite*

LEGEND

- U.S. Navy Operational System
- NOAA Operational System
- U.S. Air Force Operational System
- NASA Experimental Programs
- Customers and Users

* European Space Agency
** Japan

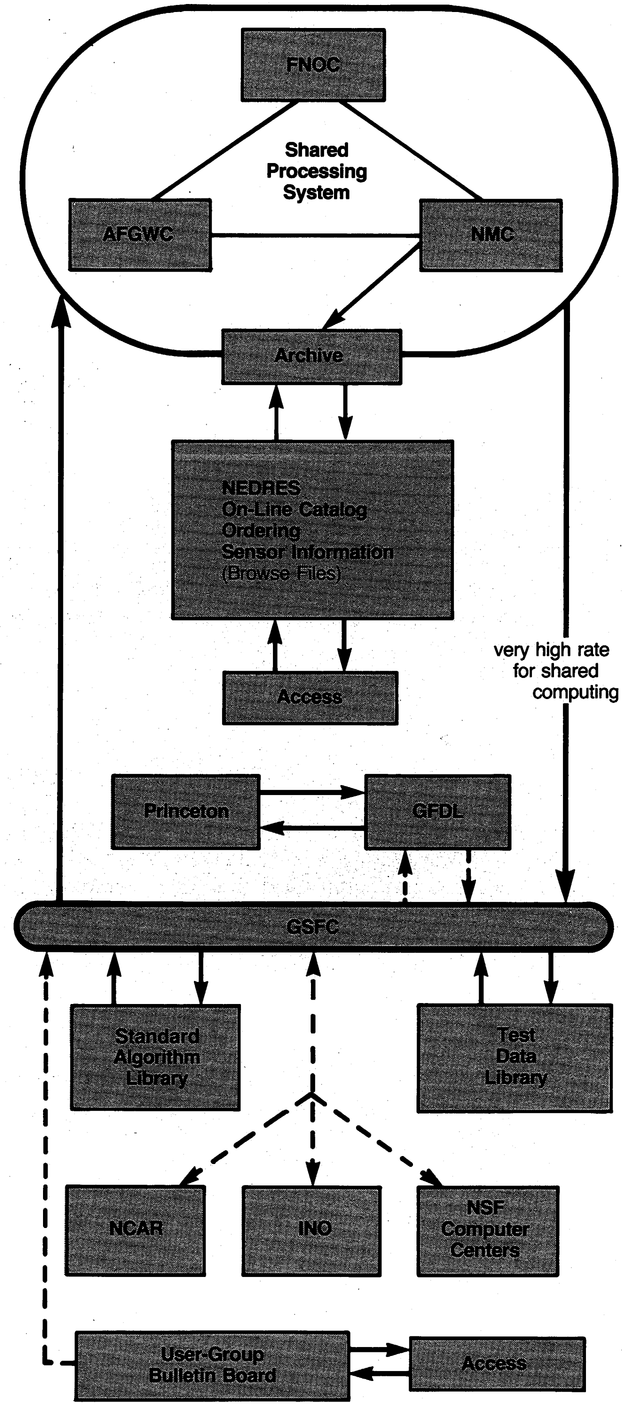
support the initial objectives of this program. The operational capabilities described in the preceding paragraph and outlined in Figure 6-2 are indicated within the top oval of Figure 6-3. A very high-rate link would be added between the National Meteorological Center and the Goddard Space Flight Center (GSFC) to permit the sharing of data and results. Two libraries, one for standard algorithms and the other for test data (both standard and site-specific), would be established at GSFC. Data would be distributed from these libraries via magnetic tapes.

A number of other centers and universities would be associated with this program. Presently envisioned entities would include NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton, the National Center for Atmospheric Research, the Institute for Naval Oceanography, and a group of universities, including those indicated in the diagram. In the minimal configuration of Figure 6-3, these centers would not receive their primary data electronically from the central system but would receive them via magnetic tapes.

As in the case of the Resources Subsystem, a central feature of this subsystem is the provision for user services. These functions in the minimal configuration would be fulfilled by NOAA's National Environmental Data Referral Service (NEDRES) for the operational data, as indicated at the top of the diagram. GSFC would carry the responsibility for the user services communications network.

The final operational network configuration indicated by dashed lines in Figure 6-3 makes four important additions: (1) it adds a high-speed data link between GSFC and the GFDL; (2) it adds data links to the National Center for Atmospheric Research, the Institute for Naval Oceanography, and participating universities; (3) it establishes a major communications node at GSFC to handle the flow of research data; and (4) it establishes a major user service center at GSFC, providing all of the functions

Figure 6-3
Ocean and Atmosphere Information Subsystem
Initial Research and Development Network



Dotted lines show future links in final operational network, with GSFC acting as node for high-speed real-time data distribution. The top oval contains the total planned operational capacity shown in Figure 6-2.

It is suggested that [the] User Services System be expanded in an evolutionary manner to serve as an integrated component of the Eos program when it becomes operational.

described earlier for the Resources Subsystem. This composite subsystem would allow multipoint, real-time access to the full range of operational, experimental, and test data, as well as to the supporting directory, catalogs, browse files, algorithm and test data libraries, user telecommunication and bulletin boards, and other activities, using GSFC as a central distribution and service center node. This is only one of many possible architectures for the ocean and atmosphere subsystem. The final configuration will depend on negotiations between participating agencies and will be based on studies of complementarity between the information system assets of the participants.

Common Features

The two subsystems described above have several common features. Most notable is the requirement for similar user support services, including inquiry and coordination communications networks. It is recommended that a single User Services System be established and operated for this program and that it serve as the prototype for such a system for the entire range of applications research in the future. Specifically, it is suggested that this User Services System be expanded in an evolutionary manner to serve as an integrated component of the Eos program when it becomes operational.

The development of this system should take full advantage of the thinking, planning, and actual work already completed and underway within the Pilot Climate Data System project, the Pilot Ocean Data System project, the Pilot Land Data System project, the Eos program, the Science and Applications Information System project, and others. Special care should be taken to ensure that the system follows the principles for space science data management identified by the National Academy of Science's Committee on Data Management and Computation. Finally, it should be carefully related to the planning of the Space Station.

An additional advantage of the common central User Services System is that it should also serve as an integrating influence for the entire system, encouraging the development of standard command languages and other user tools. It should also stimulate the use of common data formats and communications protocols to facilitate the widespread exchange of data.

Transfer to Applications Operators

The difficulties of transferring technology from a research and development (R&D) to an operational group varies widely depending on the nature of the technology and the organizations involved. If the R&D and operational groups are parts of the same organization and the R&D organization has responded to the requirements established by the operational groups, the process will generally be straightforward, prompt, and relatively painless for both parties. If the operational group has paid for the R&D, it will work even better.

If, on the other hand, an R&D group from one organization has invented and developed a new technology entirely independently of an operational group from another organization, the transfer process will be more difficult and take more time and money. Unfortunately, this has been the usual situation. In addition, if the new technology is complex and costly and is replacing an existing, well-understood, and time-tested system, the transfer process becomes even longer and more costly. If there is a budget office involved that is directing the operating agency to absorb the new technology within its existing budget, the process becomes virtually impossible. In general, if the two groups want to effect a transfer, a method will be found; if one group opposes, or simply is indifferent to a transfer, then it will not happen.

The following considerations may be helpful:

- Operational groups must be careful about introducing new technology before the technology is ready or the operating group is ready to receive it.
- Colocation of the operational staff with the R&D group during development and of the R&D staff with the operational group during the transfer, as planned between NASA and NOAA, is a very good procedure and should be encouraged. The R&D group should understand the operational constraints as early as possible, and the operational group should be involved in developing the new technology to understand operational potential. Exchange of personnel may have its problems, however, particularly if the operational and R&D staff come from organizations with markedly different salary structures and motivations, such as between a university and an industrial organization.
- Mutual understanding is required between the two groups as to the people, their training and availability, and who will be responsible for the transfer.

- The operational group should probably fund the transfer (but not necessarily the R&D). An operational organization may not be willing to allow its ongoing operations to be affected by an R&D group's ability to obtain transfer funding or by its willingness to disrupt its R&D work to support the transfer.
- There must be a very clear understanding as to which group is in charge during the various phases of the development and transfer processes, and a specific, clear, and well-understood time when a transfer of responsibility is to take place. The operational group should be responsible for the transfer for the same reasons that they should have the funding to pay for the transfer.
- The process used by NASA and NOAA to develop and operate the meteorological satellite systems is a very good model which has worked well for about 2 decades.

Transfer of the successfully demonstrated applications to operators should include the transfer of at least some portions of the information system.

Specific to this program, transfer of the successfully demonstrated applications to operators should include the transfer of at least some portions of the information system. A group wishing to place a new application into operation should not have to design the information system anew. More importantly, the new operators may miss critically important aspects of the information system that were worked out during the application demonstration and therefore be less effective or delayed in reaching operability.

For the ocean and atmosphere applications, the future operational agencies will be involved in the program from the start and, therefore, should be able to place the results into operation quite naturally and easily, assuming careful preparation and documentation. This may not be true to such an extent for the resources applications. For the sake of future operators not involved during the conduct of the program, it is critically important to proceed from the beginning with the expectation that efficient transfer of the results and processes to previously uninvolved groups will be desired.

Because parts of the information system described in the last section will be Federal agency operational facilities that will be retained by those agencies after completion of the demonstration, it is unrealistic to expect the transfer of an entire physical system to a new organization. It is helpful to distinguish between the components that may and may not be transferred. For the purposes of this plan, a distinction is made between the transfer of (1) concept and architecture; (2) guidelines, formats, and protocols for data, interfaces, software, and documentation; (3) detailed design plans; (4) actual software; and (5) actual hardware.

It should be assumed from the beginning that items 1, 2, and 3 will be transferable in their entirety and, thus, should be documented very carefully. This documentation should be oriented toward the transfer process and the operators and should involve the use of professional technical writers, editors, and layout/graphics specialists.

Most of the software (item 4), both application-independent (system, utility, service, etc.) and application-dependent (processing algorithms, models, etc.), should also be transferable. Software should be written to be as nearly machine-independent as possible to facilitate transfer to organizations using different equipment. Care should be taken to facilitate the transfer of both the software per se and its documentation.

Although some parts of the information system hardware (item 5) may be transferable, much of it will not be. As mentioned before, the large-scale computers will almost certainly remain with the agencies that offered their use for the demonstrations. For example, the User Support Information Subsystem will most likely be an integral part of the continuing archive services of the participating agencies. This, plus the fact that there may be multiple future operating agents, means that the program should use commercially available, off-the-shelf equipment wherever possible to make it relatively easy for other groups to replicate the physical capabilities.

It is also stressed that additional applications demonstrations and other research will be performed far into the future. Therefore, arrangements for providing data from the operational systems for future research purposes should be an integral part of the transfer process.

Recommendations

In connection with the planning and building of the Applications Information System, specific recommendations follow.

- *The Applications Information System should include a central Support Information Subsystem serving both the resources and the ocean and atmosphere applications.*

The functions of this subsystem should include a central directory, catalogs, browse files, bulletin board, message exchange, inquiry network, documentation, applications-independent software, and technical assistance. The inquiry network should present a single, uniform, and stable interface to the users and should be accessible via standard terminals and commercial telephone lines. The directory should provide information about the existence and location of data and methods of access to the catalogs for all remotely sensed, ancillary, in situ, test, and validation data and other data likely to be needed for these applications demonstrations. The catalogs (normally located with the data sets that they cover) should provide additional information sufficient in most cases for the investigators to be able to determine whether they wish to order the data. An on-line ordering capability should be considered.

- *The Applications Information System should be planned and built following a modular approach, with structured interfaces.*

This approach should aid future expandability, transferability to future operators, and future new research programs.

- *The Applications Information System should utilize, to the greatest extent possible, existing commercially available equipment, software, and technologies.*

The use of readily available components should decrease the time required to build the system and the probability of schedule delays and cost escalation. In addition, it should facilitate the replication of the capabilities by those who take over the operation of the applications after the demonstrations. The system should retain the flexibility to incorporate new technologies as they become available, useful, and cost-effective over the lifetime of the program.

- *The Applications Information System should adopt existing and emerging data format standards, software standards, and interface protocols.*

Standards dealing with data exchange such as those promulgated by the Consultative Committee on Space Data Systems, the Committee on Environmental and Operational Satellites, and other national and international bodies should be adopted. In addition, opportunities should be sought for improving the transportability of data, software, and hardware by the adoption of other applicable standards as they evolve.

- *The program should be planned and executed with active, participative interaction between the research activities and the potential future operators.*

The collaboration between the researchers and future operators should be started from the beginning of the program. The future operators should be expected to contribute substantially to designing the information system so that it can best meet its intended objectives, with maximum potential transportability.

- *An Applications Information System oversight function should be put in place from the beginning of the program.*

This oversight function should include membership from industry, government, and universities, with specialists from both the application and technological disciplines. This group should review the system planning, design, and operation; recommend data management policies; and provide guidance on matters such as data acquisition, retention, upgrading, and purging.

Evaluation Criteria

7

Through research proposals, NASA provides the scientific and technical communities with opportunities to contribute to NASA programs. These opportunities include proposing and conducting research, developing instruments and flight equipment, participating in data analysis, and transferring the applications technology.

There are both general and specific guidelines that should be observed in evaluating and selecting applications research proposals submitted in response to NASA solicitations. These guidelines also can aid potential participants in structuring their research proposals.

The nature of research in science and applications involves the development of techniques and the acquisition of data for the public good and in the public domain.

Types of Solicitations

NASA solicits proposals formally through the Announcement of Opportunity and invites unsolicited proposals through "Dear Colleague" letters. Unsolicited proposals are encouraged at all times, and all proposals are evaluated according to established procedures. The Announcement of Opportunity is a competitive solicitation used for major projects having specific, approved sources of funding and is published in the *Commerce Business Daily* prior to formal release to the research community. The "Dear Colleague" letter (sometimes called a Space Science and Applications Notice) is a notice that proposals are desired to meet general program objectives; it is not tied to a specific flight instrument or project. Nevertheless, unsolicited proposals can be submitted to NASA at any time for unique and innovative research that will benefit the agency's mission.

Concerns

In general, the nature of research in science and applications involves the development of techniques and the acquisition of data for the public good and in the public domain. One can envision cases in which the results from basic science are applied to a practical objective and then tailored to provide commercial benefit. Because applications-related research involves the transfer of technology to users who subsequently may develop commercial applications, program concerns exist that are uniquely different from those of basic science research.

Conflict of interest is one of the basic concerns to be considered in evaluating applications research proposals. The Office of Space Science and Applications (OSSA) intent in supporting outside investigations is to advance *research* in science and applications, not to advance commercial objectives or ventures per se. Investigations that propose the development of proprietary techniques, commercial instruments, or commercially restricted data place OSSA in conflict with the intent of its research process.

Commercial joint ventures between the private sector and the government, which involve shared costs and only address strictly commercial objectives (as distinct from research objectives), raise another concern.

International cooperation in science and applications research is normally arranged with no transfer of funds and in accordance with international agreements. Technology transfer in anticipation of the development of new international commercial

The fundamental aim of the proposed investigations is to acquire those unique ideas and capabilities that best fulfill a stated scientific, applications, and/or technological objective.

ventures raises a number of questions that need to be addressed. Generally, international transfer of critical aerospace technologies is not encouraged.

One goal of applications research is to *transfer technology* to potential government or private sector users in the United States, and therefore the conduct of this research should demonstrate the intent to involve users in some portion of the proposed effort and, ultimately, to transfer some capability to them. However, this transfer should not use government resources unfairly to compete with potential commercial ventures.

Scientific research involves *increasing scientific knowledge and understanding*. Applications research is conducted to *advance the public good in some practical sense*. Commercial programs are conducted to *promote commercial uses of space* and to create new opportunities for the industrial economy of the country.

A *public domain applications research proposal* should have, as a critical element of its final objective, the transfer of any technology and/or models that result from the research program. Applicants proposing public domain research programs could be drawn from the complete cross-section of the research community, including Federal agencies, universities, and the private sector. NASA would be one principal source of funding for public domain research proposals.

A *commercial joint venture proposal*, on the other hand, would have as its final objective the ability to provide a service or a salable product. The community proposing commercial joint venture programs would probably consist of private sector and university researchers, with funding being drawn from both NASA and the individual members of the joint venture.

Evaluation Procedures

Applications Proposals

For evaluation purposes, proposals for applications-oriented research will be divided into two broad categories:

- Public domain
- Commercial joint ventures

Figure 7-1 presents, in table format, the principal distinguishing characteristics of these two categories.

Figure 7-1
Characteristics of Public Domain and Commercial Joint Venture Proposals

TYPE	OBJECTIVE	FUNDING SOURCES	PROPOSERS	PRINCIPAL EVALUATION CRITERIA
Public Domain	Defined Technology Transfer	Government	Government, University, & Private Sector	Defined Technology Transfer Plan
Commercial Joint Venture	Enhanced Commercial Product or Service	Private Sector & Government	Private Sector & University	Defined Business Plan

Scientific Proposals

The principal elements considered in evaluating a scientific proposal are its technical and programmatic relevance to NASA's objectives, its intrinsic scientific or engineering merit, the qualifications of the investigator and the investigator's institution, and the overall cost (exclusive of the amount of cost-sharing, if any).

These same elements are fundamental and should apply as the principal elements to establish validity and credibility. The extent of evaluation will vary depending on whether a new project is proposed or the effort is a continuation of ongoing work that may require full review every 2 or 3 years.

Several evaluation techniques are used regularly within NASA. In all cases, however, proposals are reviewed by specialists in the discipline of the proposal. Some proposals are reviewed entirely in-house where NASA has particular competence; some are evaluated by a combination of in-house specialists and selected external reviewers (university, other agencies, commercial, and private); others are subject to full external peer review techniques (with due regard for conflict of interest), either by mail or through assembled panels or a combination thereof. Regardless of the technique, the final decisions are always made by NASA staff.

The fundamental aim of the proposed investigations is to acquire those unique ideas and capabilities that best fulfill a stated scientific, applications, and/or technological objective. The following are the general evaluation criteria considered:

- Scientific, applications, and/or technological merit of the investigation
- Relevance of the proposed investigation to stated scientific, applications, and/or technological objectives
- Competence and experience of the investigator and any investigative team, as an indication of the investigator's ability to successfully carry out the investigation
- Adequacy of technique or apparatus proposed, with particular regard to its ability to supply the data needed for the investigation
- Reputation and interest of the investigator's institution, as measured by the willingness of the institution to provide the support necessary to ensure the satisfactory completion of the investigation
- Cost and management aspects, to be considered in all selections.

In addition to or in lieu of the criteria listed above, additional criteria may be used. In all cases, the evaluation criteria must be germane to the accomplishment of the stated objectives.

In all cases, the evaluation criteria must be germane to the accomplishment of the stated objectives.

Applications Research Criteria

All applications research proposals, regardless of category, will first be judged according to the basic evaluation criteria for "scientific" proposals as outlined above. In addition to the scientific criteria, each proposal will be rated according to the following applications-oriented criteria:

- *NASA objectives and programs*—Does the proposed R&D forward the goals and objectives of the agency?
- *Timeliness*—When the research is completed, will the resultant application technique and/or model be useful? Will there be a great need for the application?
- *Multiple useful results* — is there flexibility, adaptability, and diversity in potential applications of the resultant technique and/or model?
- *Availability of data*—Will the data required for successful completion of the research be available? Does the proposer understand what data will be required?
- *Reasonable return on investment*—Will the new transferred technology be able to be used economically?
- *Readiness of science*—Is the state of the science in associated fields able to support the proposed technology and/or model?
- *Existence of a need*—Is there a defined need for the enhanced service and/or product? Will there be a long-term requirement for the resultant service and/or product? Does the new service and/or product serve an important national need?
- *Entrance capabilities*—Does the new capability, service, or product represent a significant technological step forward?
- *Phased program*—Is the proper review structure in place to allow for successful design and implementation of the program? Are there practical and important intermediate milestones and go/no-go decision points?

Final Criteria

Public Domain Applications

The final evaluation criteria for public domain applications proposals center on the soundness of the proposed transfer plan. The following are key criteria:

- *Well thought-out transfer plan*—Does the proposal include the recipients from the beginning through to the completion of the program?

- *Defined recipient community*—Are the recipients of the transferred technology and/or models clearly identified?
- *Technologically sophisticated recipients*—Are the recipients of the transferred technology and/or model able to apply the research results economically?

Commercial Joint Venture Applications

For commercial joint venture applications proposals, the final evaluation criteria focus on the soundness of the proposal's business plan for providing new or enhanced services and/or products resulting from the research project. Important criteria would include the following:

- *Commercialization*—Is the resultant enhanced service and/or products consistent with the goals of the commercialization of space?
- *Conflict of interest*—Is there an issue of unfair commercial advantage in the market that needs to be addressed and resolved?
- *Operational viability*—Is there a market and marketing plan that would be attractive to industry? Factors might include a method of sharing risks, the interaction of cooperation and competition, and the potential to create new industries.

Conclusion

8

The proposed Applications Strategy fosters and encourages use of space data to resolve a myriad of practical problems affecting mankind's survival on Earth, as well as to provide help with the daily decisions affecting individuals' livelihood in many fields. It is a flexible approach that will start serving users quickly, yet can change and grow to meet challenges of the future as we discover new applications not yet dreamt of.

This strategy takes an integrated and balanced approach, addressing the different needs of users in all Earth-observation fields. It offers the chance to acquire knowledge important for both science and applications and is coherent with the new multidisciplinary global approach to understanding the Earth. This strategy forges a link between NASA's extraordinary research skills and capabilities and those who need this expertise, both for routine system operations and for use by individuals possessing all levels of sophistication.

Thanks to years of superb research and engineering development by NASA, the United States harbors the most advanced space technology in the world. We need to bridge the widening gap between our technological capability and the practical uses we make of it. This Applications Strategy will help NASA to promote the use of space-based data both for economic gain and for the improved welfare of mankind.

Appendix A Summary of NASA Science Program

NASA's Earth Science and Applications Division (ESAD) operates a science-driven program; its primary overall goal is to investigate and understand the Earth as a system from its interior through the magnetosphere. NASA carries out general research and development and promotes civilian satellite technology, with congressionally mandated responsibility for Earth Science research missions from space, including those of broad scientific scope. The Division's research is aimed at advancing our knowledge of land, atmospheric, oceanic, and biospheric processes in order to understand our environment and ultimately to predict global change induced either naturally or by human activity.

The scientific advances occurring through satellite remote sensing are inextricably linked with practical applications. Basic science research, with its advanced concept studies, development of algorithms and models, and in situ tests and demonstrations, provides the basis for the outgrowth and spinoff of an essentially limitless number of potential applications. For example, the canopy yield models so crucial for climate prediction also can be of benefit for forecasting crop production, estimating forest yield, and eventually for assessing the animal/human carrying capacity of vulnerable land environments.

ESAD Research Programs

Research and technology developments carried out by the various ESAD branches offer a wide and extensive range of potential applications for users in industry, government, or universities, as well as for the operational community. The discipline branches consist of Geodynamics, Land Processes, Oceanic Processes, Atmospheric Dynamics and Radiation, Atmospheric Chemistry, including research programs on the upper atmosphere and troposphere, and Space Plasma Physics. Types of potential applications vary, depending on the scope and mandate for activities within each particular branch. The following descriptions provide a general overview of the branches and of some existing and potential areas of application.

Geodynamics

The Geodynamics Program goal is to understand the dynamics of the solid Earth, particularly the processes that result in movement and deformation of the tectonic plates, and to improve measurements of the Earth's rotational dynamics and its gravity and magnetic fields. This is a science program, with applications occurring primarily as a spinoff. The program's major application lies in the area of earthquake prediction: remote sensors are becoming exquisitely accurate in their ability to measure large-scale surface motion. The Crustal Dynamics Program measures the development and release of strain on a regional scale, specifically within the California earthquake zone. Ocean floor structure is also being studied using radar altimetry data.

Techniques used include satellite laser ranging (SLR) and Very Long Baseline Interferometry (VLBI), with a goal of achieving ½ to 1 cm per year measurement accuracy instead of the current 2-3 cm accuracy. As equipment reaches an operational stage, it is turned over to other Federal agencies (e.g., mobile VLBI facilities have been transferred to the NOAA National Geodetic Survey). NASA works extensively with the U.S. Geological Survey (USGS), the Federal Emergency Management Agency, the Department of Defense, Defense Mapping Agency, NOAA, and the National Science Foundation. A major future effort now being planned, called the Geopotential Research Mission (GRM), will provide an accurate gravity field for the Earth. The International Geomagnetic Reference Field (IGRF) is based on NASA Magsat measurements, and future IGRF revisions will result from the proposed GRM and Magnetic Field Explorer.

Land Processes

One fundamental goal for this program is to establish the relationship between Earth surface properties and remotely sensed parameters. Program components include Terrestrial Ecosystems, Hydrology, Geology, and basic remote-sensing science. Among the relationships being investigated are vegetation productivity as measured by optical instruments, silicate abundance (clays) by thermal infrared measurements, surface mineralogy from near infrared instruments, and the development of vegetation canopy models based on microwave measurements. Current research activities include monitoring of the African drought, studies of bioproductivity and land cover, interannual variations in productivity linked to the carbon dioxide cycle, and acid stress assessment in forests of Germany and Vermont.

From the applications standpoint, the Land Processes Program is expected to improve existing techniques for mapping land surface features, vegetation, and structure, and for inferring the presence of subsurface water reserves and deposits of minerals, oil, and gas. Remote-sensing technology can be significant for detecting and managing many land, water, and mineral resources on a worldwide scale, including crop monitoring, forest range and watershed management, land use planning, and wetlands productivity. These renewable and nonrenewable resources are crucial for the quality of life on Earth, because they determine the natural carrying capacity of the land, agricultural potential, urban growth limits, fuel and mineral production, and ecosystem balance.

The program utilizes both airborne and shuttle platforms as a means of testing designs and improving the measurement capabilities of potential satellite sensors. Planned shuttle experiments and current airborne sensors include the Shuttle Imaging Radar (SIR-C), Shuttle Imaging Spectrometer Experiment, Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS), Airborne Imaging Spectrometer (AIS), Thermal Infrared Multispectral Scanner (TIMS), Advanced Solid-State Array Sensor (ASAS), L-Band Pushbroom Microwave Radiometer, Airborne LIDAR, and the Airborne Laser Topographic Profiler. The NASA Land Program coordinates with the Department of Agriculture, USGS, and other national agencies and maintains a leadership role, including the conducting of field experiments, for the International Satellite Land Surface Climatology Project (ISLSCP).

A current effort supports intercalibration of Landsat, AVHRR, and SPOT data, which will greatly enhance space-based land science research involving diverse temporal and spatial scales. NASA is also working with EOSAT to identify useful infrared and visible band measurements for a future Landsat-type mission. An important future plan involves coordination of all NASA pilot land data systems to permit convenient and standardized access for multidisciplinary research.

Oceanic Processes

The goal of the Oceanic Processes Program is the development, evaluation, and application of spaceborne observing techniques to advance the understanding of the fundamental behavior of the oceans, as well as to assist users with the use of operational systems. Strong emphasis goes to development of spacecraft and sensors in this relatively new field for remote sensing. Program components consist of Physical Oceanography, Biological Productivity, and Polar Oceans Processes.

The branch maintains close working relationships with operational oceanographers, particularly the Navy. This allows NASA to derive scientific benefit from programs funded by the Navy, as well as meeting the Navy's need for scientific support from NASA. Seasat ocean monitoring techniques have been transferred to NOAA and to potential users in private industry. Oceanographic remote sensing serves a diverse applications community of both public and private interests. The technology is useful for polar ocean/ice operations, forecasting and monitoring of ocean conditions and weather, mapping of off-shore oil platforms, and management of fishery production and operations.

Seasat (1978), the first satellite exclusively devoted to remote sensing for oceanographic research, provided measurements of wind speed, wave height, and sea surface temperature. Primary spaceborne measurements currently used are ocean color (productivity) from the Nimbus-7 Coastal Zone Color Scanner (CZCS), sea surface temperature from the NOAA Advanced Very High Resolution Radiometer (AVHRR), sea surface roughness and topography from satellite scatterometers and altimeters, and sea-ice cover and motion from microwave radiometers and synthetic aperture radar (SAR). An Alaskan SAR facility is now under development.

A major future event will be the launch of the Ocean Topography Experiment (TOPEX/POSEIDON), a dedicated altimeter mission to be conducted jointly with the French Space Agency (CNES), in conjunction with NASA's scatterometer (NSCAT) planned to fly in the early 1990s. This 3-year mission will map the circulation of the world's oceans from detailed measurements of sea surface topography. Combined with ocean surface winds to be measured by NSCAT, TOPEX/POSEIDON will for the first time provide the global description of ocean circulation needed for improved climate prediction.

NASA is also proposing a new ocean color instrument, which would contribute significantly to our understanding of ocean productivity. The modeling of ocean productivity is expected to start by the early 1990s. During 1986, NASA's pilot Ocean Data System (NODS) became an ocean science support facility. This distributed NASA system will contain a prototype data archive with a network of links to outside users.

Atmospheric Dynamics and Radiation

This program seeks to improve our current understanding of atmospheric dynamics on a global (1-14 days and 50-10,000 km distances) to mesoscale (a few hours and 10-200 km distances). An additional component, the Climate Research Program, deals with extended time intervals ranging from weeks to decades on a regional to global scale. This core research/analysis effort focuses on problems in the atmosphere addressable by space technology and currently supports nearly 450 studies concerned with space-based research. This balanced atmospheric program to develop advanced remote-sensing systems includes laboratory and field measurements, airborne and balloon concept testing, conceptual studies, and development of algorithms, data processing techniques, and atmospheric models.

Technology developed through NASA-sponsored atmospheric research has led to major improvements in weather forecasts. News reports can now routinely report 3- to 5-day forecasts, impossible only a few years ago. The Atmospheric Dynamics and Radiation Program works closely with the operational community, particularly the NOAA National Weather Service (NWS) and the National Environmental Satellite, Data, and Information Service (NESDIS). Improved weather forecasts on a global, regional, and local scale offer innumerable practical applications, from hurricane or flood warnings to prevention of freezing in fruit orchards to timing of crop harvests. Examples of specific applications from the research program include the transfer of radiation software to NOAA/NWS for use in their national weather prediction model, the incorporation of numerical inversion techniques into the NOAA temperature/moisture retrieval process, and the incorporation of an ocean surface wave-height model into the NOAA wave-height forecast. NASA research in developing algorithms and data processing techniques has also contributed significantly to forecast improvements.

In focused support of applications research, NASA participates in the Storm-Scale Operational and Research Meteorology (STORM) project to be conducted from 1985 to 2000. The STORM project seeks to increase understanding and development of advanced techniques for improving storm weather predictions and warnings, and uses intensive field data collection across the United States. Another interesting field activity is the Microbursts in Severe Thunderstorms (MIST) project, which measures and studies conditions causing the small-scale downdrafts that can affect airplanes on landing or taking off.

The NASA Nimbus spacecraft provided much of the experimental foundation for developing operational sensors now used by NOAA. Sensors supported by NASA, now in operation, include infrared and microwave atmospheric sounders (HIRS and MSU), and an imaging radiometer (AVHRR) on the NOAA polar-orbiting spacecraft with its counterparts (VISSR, VAS) on the NOAA geosynchronous-orbiting spacecraft. NASA continues to support improvements in atmospheric sensors and is participating in development of the next generation of advanced microwave sounding units (AMSU).

The Atmospherics Dynamics Program is now working to develop active remote-sensing systems, making use of the very rapid advances occurring in laser and radar technology. These offer great promise for extracting information not available through passive sensing instruments, whose capabilities are now stretched close to their theoretical limits. Instruments under development or study include Light Detection and Ranging (LIDAR) instruments for wind measurements; a satellite radar instrument for measuring direct precipitation; a day/night lightning mapper; and an experimental sensor on the GOES-Next spacecraft that would permit the relating of lightning discharge rates to precipitation rates and to storm development processes, including measurement of storm severity.

Atmospheric Chemistry (Upper Atmosphere/Troposphere)

The Atmospheric Chemistry Program is a large, comprehensive research program, with NASA playing a leadership role as mandated by Congress under the Clean Air Act of 1976 and the FY 1976 NASA Authorization Act, which modified the Space Act of 1958. This research program seeks to improve current knowledge of the fundamental physics, chemistry, and transport processes from the ground to 80 km, including the troposphere, stratosphere, and mesosphere. It also seeks to assess as accurately as possible the perturbations to the atmosphere, particularly the ozone layer, caused by man's activities. Current studies are looking at the combined effects of continued increases in the atmospheric concentrations of chlorofluorocarbons, carbon monoxide, carbon dioxide, methane, nitrous oxide, and the nitrogen oxides.

The Tropospheric Chemistry Program aims to understand the chemical cycles that control the composition of the troposphere and to assess how susceptible the global atmosphere may be to chemical change. Tropospheric chemical changes can affect global hydrological processes, the cycling of nutrient compounds, the accumulation of infrared active gases in the atmosphere, rain and snow acidity, and the rate of ozone depletion in the stratosphere and mesosphere caused by man-made chemicals.

Although the Atmospheric Chemistry Program appears to be directed toward a specific application (ozone depletion, including the "greenhouse effect"), a very broad program of basic science is actually required. Unlike many applications, which seem fundamentally local in nature, the ozone problem concerns a specific application on a global scale. It is a balanced research program consisting of field measurements, laboratory studies, theoretical studies, and data interpretation, with heavy emphasis on development of two- and three-dimensional models of the atmosphere. A large atmospheric chemistry field experiment was recently completed over the Amazon tropical rain forest, and in 1986 a major field experiment was made on several species in the nitrogen family.

A variety of in situ and remote-sensing techniques are used to determine the distribution of ozone and other trace species in the atmosphere. Data sets from satellites now generally available to users include Nimbus-4, -6, and -7; the Solar Mesospheric Explorer (SME); Stratospheric Aerosol and Gas Experiment (SAGE); and NOAA and Department of Defense satellites. Improved instruments are needed with sensitivity in the parts per trillion and quadrillion range to measure gases and trace species in the troposphere.

Shuttle payloads, both flown and planned, contribute significantly to our understanding of the chemical composition and dynamics of the Earth's atmosphere. The Upper Atmosphere Research Satellite (UARS), scheduled for launch in 1991, will measure solar ultraviolet and energetic particle input to the atmosphere and re-radiated x-rays. It will also measure the altitude density profiles for many chemical species and determine winds by direct observation at altitudes of 10 to 100 kilometers.

Direct NASA Applications Activities

Scientific research carried out by ESAD programs results in an extremely diverse range of potential applications for Federal agencies, the private/commercial sectors, other nations, and international entities. Transfer of technology can occur through a variety of methods. Ways in which NASA transfers research to operational and applications users include the following:

- Support of applications research by universities and other groups through the research program of the ESAD disciplines.
- Development and transfer of sensor and spacecraft technology to NOAA's operational satellite program for weather forecasting, international search and rescue missions, and other purposes. Spacecraft supported by NASA have included TIROS/NOAA, GOES, and Landsat.
- Cooperation with the U.S. Navy in the development and transfer of space technology. An example is NASA's transfer of data processing and interpretive techniques for the Seasat Scanning Multichannel Microwave Radiometer (SMMR) to the Oceanographic Numerical Fleet Command.
- Support for technology transfer programs of international agencies. An example is NASA's cooperation with the U.S. Agency for International Development

(AID) to assist Bangladesh with an improved space-based system for monitoring and predicting local weather and crop resources.

- Cooperative agreements with the international community, particularly through the United Nations. For improving access and management of globally distributed data about Earth resources, NASA supports a pilot project to develop a Global Resources Information Data Base (GRID), comprising a distributed archive, data base, and data processing facilities linked by the Intelsat Communications Satellite System.
- Cooperation in international Earth science research programs. Currently, NASA has an extensive role in the international Crustal Dynamics Project; the World Ozone Program; the Global Environment Monitoring System (GEMS); and the World Climate Research Program, comprised of the Tropical Ocean Global Atmosphere Program (TOGA), the International Satellite Cloud Climatology Project (ISCCP), and the International Satellite Land Surface Climatology Project (ISLSCP). Projects in the planning stage include the World Ocean Circulation Experiment (WOCE), the International Geosphere-Biosphere (or Global Change) Program (IGBP), Global Ocean Flux Study (GOFS), and the Global Tropospheric Chemistry Program (GTCP).

The names of these international research programs alone suggest why a precise demarcation between pure Earth science research and its applications is so difficult. Clearly, scientific research on both global climate and atmospheric ozone have a direct, crucial bearing on the quality of life on Earth, including our capacity to feed global populations and our ability to predict and shape changes caused by mankind in the life-sustaining atmosphere.

Commercialization of Space Technology

How the commercial sector in the United States can achieve maximum benefit from our advanced remote-sensing technology is a topic now being carefully analyzed by Congress, the Executive Branch, Federal agencies, and private concerns. NASA is strongly committed to the transfer of remote-sensing technology to the private sector and is currently involved in the following activities:

- Discussions with the Earth Observation Satellite Company (EOSAT), which is now operating the Landsat system, in order to define the role of NASA with regard to EOSAT and its technological research needs;
- Assisting Congressional staffs in their review of the Landsat legislation, which initiated the commercial approach to remote sensing, by identifying issues and possible modifications to the legislation;
- Developing a relationship with the Space Remote Sensing Center at the Institute for Technical Development in Bay St. Louis, Mississippi, a new entity funded by NASA's Office of Commercial Programs to ensure compatible and consistent approaches to the private sector;
- Initiating the sale of experimental data to the private sector through a competitive process, exemplified by the award of Large Format Camera data sale rights to a private company as required under Public Law 98-365;
- Developing, with other Federal agencies, a national plan for commercial remote sensing as the second in a series of biannual reports to Congress on the current status of remote-sensing research and development;
- Developing, with the sponsorship of the SAAC Subcommittee on Remote Sensing, a viable, practical approach for NASA applications research over the coming decade.

Appendix B Definition of Terms

To facilitate a common base of understanding, the following terms are defined:

Remote-Sensing Technology: Any one or all of a set of capabilities that facilitates the acquisition and utilization of remotely sensed data. Includes sensors and platforms, data handling systems, ground truth and data interpretation techniques, processing algorithms, and scientific models.

Earth Remote-Sensing Applications: The use of remote-sensing technology to meet the mission objectives of public entities or the objectives of the private sector. Incorporates remotely acquired data as one element in an effective solution to a problem that often requires critical and/or immediate information about the Earth and its environment, frequently in the context of a local geographic area. May have immediate or potential commercial value.

Technology Transfer: The transfer of remote-sensing technology, developed specific to an application, from the office that developed the technology to user organizations. Generally considered complete when utilization occurs in an operational mode.

Information System: A comprehensive, computer-based capability that facilitates data organization and access, archiving, processing and analysis, and retrieval and distribution for space- and ground-based Earth data.

Subsystem: One of a series of components that combine to perform the system function.

Demonstration: An activity or project to verify and validate with a potential user the capability and utilities of a limited research system for performing an application function.

Operational: An operational system exists outside the research arena and is usually controlled and managed by government or industry, with requirements, decisions, and priorities based on the needs of the marketplace; it is characterized by continuity and routineness of data; the system and its data are repetitive (not one of a kind) , reliable, well-characterized, standardized, stable (changing only after careful consideration), and timely in delivery of the product.

Appendix C
Methodology

Introduction

This section outlines the process used to develop the applications strategy. It is intended as a guide for planning complex tasks, which require the need for a consensus from multidiscipline constituents and have a short time frame in which to produce meaningful direction.

This strategy was developed under the sponsorship of the NASA Earth Science Applications Division and the Remote-Sensing Subcommittee of the Space Applications Advisory Committee with the assistance of 24 senior scientific, academic, and business professionals knowledgeable in remote-sensing technology and its applications, and familiar with the remote-sensing user community.

In developing the strategy, extensive consideration was given to the logic and design of a planning process that would ensure that (1) both long-range direction and near-term milestones and success indicators were produced and (2) involvement and consensus by the remote-sensing community on these goals and objectives were achieved. This demanded a structured planning process and interdisciplinary problem solving.

Structured Approach

Generating broad, long-range goals was the first step in developing the strategy. These goals provided the ultimate direction and framework for defining near-term applications research objectives. As important as defining the goal was the need to gain agreement on the underlying assumptions about the future of remote sensing: the environmental, political, and economic context. Together, the assumptions and goal became the criteria for selecting the near-term objectives that would help direct NASA's remote-sensing applications research over the next 10 years.

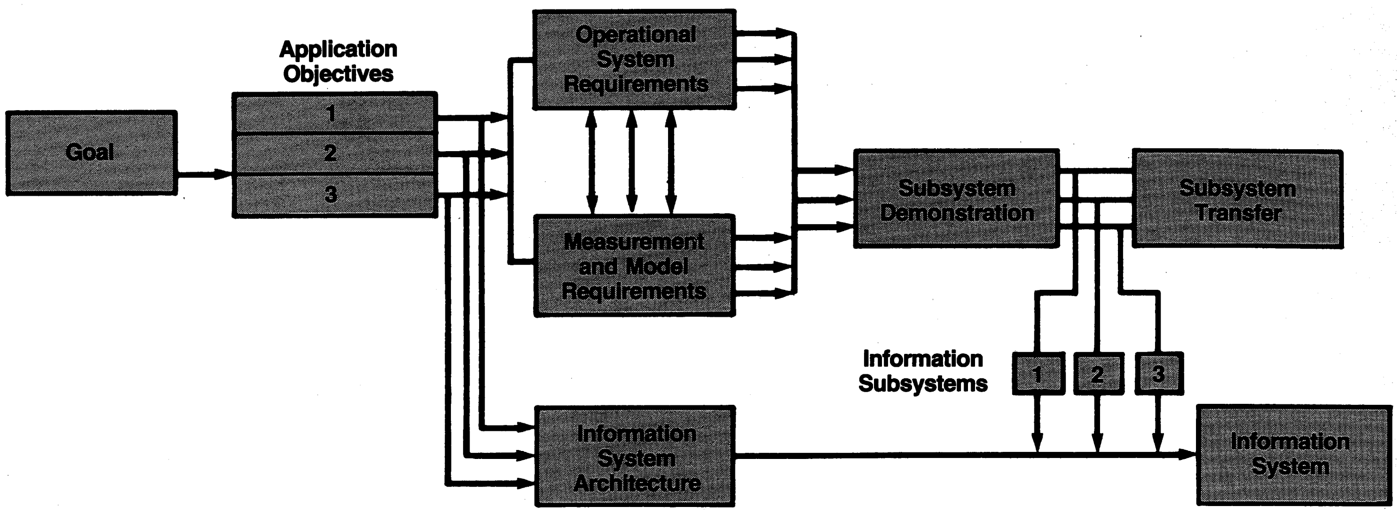
An important goal in this process was to tie the remote-sensing applications strategy to major studies and reports developed since the Congressional mandate: "Earth Observing System Data and Information System: A Report of the Eos Data Panel," "Earth System Science: A Program for Global Change," and "Space-Based Remote Sensing of the Earth and Its Atmosphere." This meant stepping out of the pure discipline approach to remote sensing and addressing multidisciplinary applications problems.

The remote-sensing technical advisors had to be familiar with the state of the science as well as be current in the applications needs of the remote-sensing user community. The nature of the long-range goal (information systems) meant they must keep one foot in their discipline areas and one in the arena of information systems. They must produce the equivalent of a near-term remote sensing applications research agenda while defining users' systems analysis requirements. Likewise, the information systems experts must, in real time, become familiar with the remote-sensing applications areas to extract the system requirements. Only then can they define the information system architecture requirements.

The task of the workshop process became:

To assist the technical advisors' work within a 10-year time frame on applications programs that would further the development of integrated information systems.

Figure C-1
Process Flow Diagram



Four-Stage Development Process

To assist the advisors, this complex task was broken into four concrete stages that are analogous to the development stages of an applications program. In addition, the information system development process was defined and worked in parallel and interactively with these applications stages. These stages are outlined in the flow diagram in Figure C-1.

First, the applications objective was written according to specifications. Second, measurement and model requirements were defined. These were the data and measurement needs (in 6- to 12-month intervals) and the analytical requirements to move the technology and achieve the objective. Third, the operational requirements identified the variety of social, economic, political, and operating environment factors in which the application must eventually survive. At this point the original objective was reviewed and modified to ensure its compatibility with the "real world." Fourth, the demonstration stage of the application capability was outlined, namely, the mission success criteria. This ensured that the application objective was considered in terms of what a final product should look like. Finally, a transfer process was defined for each objective to identify what provisions were needed to transfer the capability to a user.

The information system advisors assisted the applications advisors to define the implications of their applications objectives for developing the information systems. This included identifying data sources, interfaces, standard formatting requirements, data rate, and accessibility, archiving, and catalog needs.

Once this systems analysis was drafted, architecture requirements could begin to be defined and validated.

Mechanics of the Process

In developing this strategy, a highly structured consensus planning model was used with emphasis on (1) clearly defining and communicating the task, operating assumptions, and desired product and (2) managing the planning process to maximize expertise and minimize frustration with the complexity of the task. This meant dividing the task into concrete deliverables, defining and agreeing on terms of reference and operating assumptions before the planning began, and structuring time to allow quality small-group interaction and large-group review. To this end, meeting agendas for all sessions were detailed and reviewed at the start of each session to ensure that expected outcomes and schedules were clear. Perhaps unique to this workshop was the use of detailed worksheets to provide assistance in organizing each set of tasks and to ensure consistency of approach and product. In addition, for synergy, meeting facilitators assisted each task team in the process of defining requirements, reporting results, and managing conflict.

Support Materials and Briefings

Extensive briefing materials were provided to the technical advisors. These materials outlined the objective of the planning process, the desired outcome, definition of terms, and goal-setting instructions. In addition, overviews of current science programs, legislation, and executive policy provided background for planning. These preworkshop materials and structured briefings were essential to the effective use of limited time.

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Acronyms

AFGL	Air Force Geophysics Laboratory
AFGWC	Air Force Global Weather Central
AID	Agency for International Development
AIS	Airborne Imaging Spectrometer
AO	Announcement of Opportunity
AMSU	Advanced Microwave Sounding Unit
ARS	Agriculture Research Service
AVHRR	Advanced Very High Resolution Radiometer
CCSDS	Consultative Committee on Space Data Standards
CEOS	Committee on Earth Observations Satellites
CNES	French Space Agency
CZCS	Coastal Zone Color Scanner
DCP	Data Collection Platform
DCS	Data Collection System
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
EEZ	Exclusive Economic Zone
Eos	Earth Observing System
EOSAT	Earth Observing Satellite Company
ERBS	Earth Radiation Budget Satellite
ERL	Environmental Research Laboratories
ERS-1	First Earth Remote-Sensing Satellite (ESA)
ERS-1	Earth Resources Satellite (Japan)
ESA	European Space Agency
ESSC	Earth System Sciences Committee
FNOC	Fleet Numerical Oceanography Center
GARP	Global Atmospheric Research Program
GDHS	Ground Data Handling System
GDR	Geophysical Data Record
Geosat	Geodetic Satellite
GFDL	Geophysical Fluid Dynamics Laboratory
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Experimental Satellite
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System
HIRIS	High Resolution Infrared Imaging Spectrometer
HIRS	High Resolution Infrared Sounder
INO	Institute for Naval Oceanography
INSAT	Indian National Satellite
JHUAPL	Johns Hopkins University Applied Physics Laboratory
JIC	Joint Ice Center
JPL	Jet Propulsion Laboratory
Landsat	Land Remote Sensing Satellite
MCSST	Multichannel Sea Surface Temperature
Meteosat	Meteorological Satellite

MMS	Minerals Management Service
MODIS	Moderate Resolution Imaging Spectrometer
MOS-1	Marine Observation Satellite (Japan)
MSS	Multispectral Scanner
MW	Microwave
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NEDRES	National Environmental Data Referral Service
NESDIS	National Environmental Satellite, Data, and Information Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NODS	NASA Ocean Data System
N-ROSS	Navy Remote Ocean Sensing System
NSCAT	NASA Scatterometer
NWS	National Weather Service
OPC	Ocean Products Center
OSSA	Office of Space Science and Applications
OPTOMA	Ocean Prediction Through Observation, Modeling, and Analysis
PN	Panchromatic (SPOT)
POES	Polar-orbiting Operational Environmental Satellite
PSCN	Program Support Communication Network
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SEAS	Shipborne Environmental (Data) Acquisition Systems
Seasat	Sea Satellite
SLR	Satellite Laser Ranging
SPAN	Space Physics Analysis Network
SPOT	Systeme Probatoire d'Observation de la Terre (France)
SSM/I	Special Sensor Microwave Imager
SYNOP	Synoptic Ocean Prediction
TIMS	Thermal Infrared Multispectral Scanner
TIR	Thermal Infrared
TM	Thematic Mapper (Landsat)
TOGA	Tropical Ocean Global Atmosphere Program
TOPEX	Ocean Topography Experiment
UARS	Upper Atmosphere Research Satellite
UCAR	University Corporation for Atmospheric Research
URIP	University Research Initiative Program
USDA	United States Department of Agriculture
USAF	United States Air Force
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
VNIR/SWIR	Visible Near Infrared/Shortwave Infrared
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch
XS	Multispectral Scanner (SPOT)